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### TEST MODULES FOR NETWORK TEST INSTRUMENT UTILIZING CONTAINERS

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#### Abstract

A test instrument provides field technicians with resources to support multiple aspects of network testing. The test instrument includes multiple, integrated and removably connectable modules such as a base module, a battery module and other modules that perform different tests on a network. Threads for a network test application can run on multiple modules of the test instrument. Containers are created on each of the modules to run the threads. An application name discovery and routing service (ANDR) is created in each of the containers. Also, an ANDR database is maintained by the ANDRs and the ANDR database identifies the container running each thread. The ANDRs route command and control messages between each other to utilize threads of the network test application running in other containers based on one or more of the entries in the ANDR database.

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## **Background/Summary**

PRIORITY [0001] The present patent application is a Continuation of commonly assigned and co-pending U.S. patent application Ser. No. 18/113,287, filed on Feb. 23, 2023, which claims priority to U.S. Provisional Patent Application No. 63/313,421, filed on Feb. 24, 2022, the disclosures of which are hereby incorporated by reference in their entireties.

### **BACKGROUND**

[0002] In a modern data center, there are thousands of links, cables, transponders, and connections, which can each be a potential point of failure. A few examples of test use cases for data center operators are described below and are grouped into external or internal test requirements.

[0003] An example of an external test use case relates to data center to data center interconnect (DCI). Due to the importance of the data stored in data centers, most data center operators (DCOs) back up data to yet another data center via high-capacity connections to ensure quick disaster recovery (DR). To maintain the integrity of those valuable connections and to verify service level agreements (SLAs), a DCO must perform tests on Ethernet line rates, e.g., up to 400 Gbps (400G) or higher, as well as testing optical transport networking circuits, coarse wavelength division multiplexing (CWDM) circuits, and/or dense wavelength division multiplexing (DWDM) circuits. Data centers with 400G Ethernet circuits employ a different modulation scheme (pulse amplitude modulation 4 level (PAM-4)) than lower line rates, and different transmission characteristics, and the testing has to accommodate these modulation schemes and new interfaces such as non-return-to-zero (NRZ) interfaces. Critical tests include industry-based: y Enhanced RFC-2544, Y.1564 SAM Complete and RFC-6349 True Speed. In addition, with such big and critical circuits connecting data centers, testing the underlying fiber integrity on those circuits is also prudent.

[0004] Another example of an external test use case relates to 200G Data Center Interconnects (DCIs). To address ever growing data loads, many DCOs are using higher order modulation to create 200G wavelengths over their DWDM systems, thereby doubling the capacity over the same fiber. While beneficial, the danger is not testing the system before adding live traffic to it. There may be limitations on a particular wavelength that prevent it from achieving a 200 Gbps transmission rate, and the limitations cannot be known without stress testing the wavelength before putting it into service. Many DCOs don't test these new 200G links simply because they don't have the test capability. It's a challenge that extends from the data layer down to the optical transmission layer when validating optical signal to noise ratio (OSNR) and optimizing launch power levels to minimize bit error rates.

[0005] An example of an internal test use case relates to active optical cables (AOCs) and Direct Attach Copper (DAC). AOCs are widely used in DCs but they are difficult to test for errors because the optics are fused to each end. DAC are copper cables but pose the same testing challenge. When a link will not come up, many DCOs will replace an AOC hoping that it was the root of the problem without knowing for sure. AOCs are expensive and DCOs want to avoid mistakenly throwing away good AOC cables. AOC/DAC cables and breakout cables should be tested against transmission defects with a Bit Error Rate test.

[0006] Another example of an internal test use case relates to testing pluggable, optical transceiver modules which may be on the ends of the AOC cables. Quad Small Form-factor Pluggable units

(QSFPs) and small form-factor pluggable units (SFPs) are examples of optical transceiver modules that connect to fiber-optic cables and may support up to 100 Gbps or higher optical transmission. These transceiver modules should be tested to ensure they are working optimally.

[0007] Conventional test instruments may not be able to perform all the tests needed to properly confirm operation of the thousands of links, cables, transponders, and connections, which can each be a potential point of failure, in a modern data center. As a result, DCOs often have to rely on many different test instruments and become familiar with the operation of the many different test instruments, or DCOs forego certain tests which can result in various DC failures and outages.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Features of the present disclosure are illustrated by way of examples shown in the following figures. In the following figures, like numerals indicate like elements, in which:

[0009] FIG. 1 shows a high-level architecture of containers, according to an example of the present disclosure;

[0010] FIG. 2 shows a protocol that is followed to register a network test application, according to an example of the present disclosure;

[0011] FIG. 3 shows a flowchart for running a network test on the test instrument and describes the messages exchanged to run the network test, according to an example of the present disclosure;

[0012] FIG. 4 shows initialization of components of a container system, according to an example of the present disclosure;

[0013] FIG. 5 shows initialization of a network test application running in a container, according to an example of the present disclosure;

[0014] FIG. 6 shows a process when a network test is launched, according to an example of the present disclosure;

[0015] FIG. 7 shows control groups, according to an example of the present disclosure;

[0016] FIG. 8 shows that a container may be a combination of namespaces and control groups, according to an example of the present disclosure;

[0017] FIG. 9 shows a control group for a container can be used to control particular hardware resources, according to an example of the present disclosure;

[0018] FIG. 10 shows a multi-core distributed service architecture, according to an example of the present disclosure;

[0019] FIG. 11 shows a service state flow, according to an example of the present disclosure;

[0020] FIG. 12A illustrates a perspective view of a test instrument including a base module and an input/output (I/O) device, according to an example of the present disclosure;

[0021] FIG. 12B illustrates a back side view of a base module, according to an example of the present disclosure;

[0022] FIG. 12C illustrates a top view of a base module, according to an example of the present disclosure;

[0023] FIG. 12D illustrates a bottom view of a base module, according to an example of the present disclosure;

[0024] FIG. 12E illustrates an exploded perspective view of a test instrument including an input/output (I/O device), a base module, and dual expansion modules, according to an example of the present disclosure;

[0025] FIG. 12F illustrates an exploded perspective view of a test instrument including a removably connected first solution module, according to an example of the present disclosure;

[0026] FIG. 13 illustrates a perspective view of removably connectable smart battery module in the form of an expansion module, according to an example of the present disclosure;

[0027] FIG. 14A illustrates a high-level system diagram of a base module and an I/O device, according to an example of the present disclosure; and

[0028] FIG. 14B illustrates a high-level system diagram of a base module a removably connected to a first solution module, a second solution module, and an I/O device, according to an example of the present disclosure.

#### DETAILED DESCRIPTION

[0029] For simplicity and illustrative purposes, the present disclosure is described by referring mainly to examples thereof. In the following description, details are set forth in order to provide an understanding of the present disclosure. It will be readily apparent however, that the present disclosure may be practiced without limitation to these details. In other instances, some methods and structures have not been described in detail so as not to unnecessarily obscure the present disclosure.

[0030] Throughout the present disclosure, the terms “a” and “an” are intended to de at least one of a particular element. As used herein, the term “includes” means includes but not limited to, the term “including” means including but not limited to. The term “based on” means based at least in part on.

[0031] According to an example of the present disclosure, a test instrument provides field technicians with resources to support multiple aspects of installing and maintaining high-capacity networks, including 400G networks. The test instrument includes interfaces to test fiber optic cables, QSFPs and SFPs, etc. The test instrument is also referred to as a network test instrument.

[0032] The test instrument may also be used for cell site testing, including testing for installation and maintenance of cell sites, and testing related to fiber optic cables (i.e., fiber) and optical signals, Radio Frequency (RF) signals, coaxial cables (i.e., coax) and antennas.

[0033] The test instrument provides multiple technical advantages over existing tools. The test instrument provides improved efficiency because it may replace multiple independent tools as well as provide additional measurements and insights that can improve installation and maintenance. In an example, the test instrument is modular, and different hardware modules can be added to the test instrument to provide different types of testing or to provide additional modules supporting multiple simultaneous tests that are the same. Thus, the test instrument is scalable, because modules can be added to accommodate new testing requirements.

[0034] Another technical advantage of the test instrument is that it can conserve hardware resources, including data storage, processing cycles, and input/output when multiple modules are connected to the test instrument. For example, the pluggable hardware modules may each run applications and threads. An application, also referred to as a network test application, is comprised of software, and is executable by hardware, including one or more processors and memories, of the test instrument. In an example, the test instrument includes a base module and/or pluggable modules connected to the base module, and each module having hardware resources including a processor and memory that can be used to run threads of the network test application. The pluggable modules may also be referred to as removable modules that are removably connected to the base module.

[0035] The network test application can be executed to perform a network test. Examples of network tests that can be performed by the test instrument are described below. Some nonlimiting examples include but are not limited to: an optics self-test for testing QSFP and SFP pluggables, high-speed cable testing for data centers, RFC 2544/Y.1564 testing, and optical transport network (OTN) testing. Also, the network testing may include tests performed by a 400G module with PAM4 400GE, 200GE, 100GE (no FEC or KR4 FEC), and 50GE with SFP56 testing. A 100G module supports independent dual tests for different protocols and for intermediate rates like 10GE and 25GE. An OTDR module can perform OTDR testing on fiber optic cables. Ethernet service activation testing includes: a QuickChek automated test that validates end-to-end configurations; a pre-check test for RFC 2544 or Y.1564; and a Y Enhanced RFC 2544 automated up test with for

validating key performance indicators (KPIs), concurrently measuring throughput, frame delay, and frame delay variation in addition to frame loss and committed burst size (CBS). Optical spectrum analysis testing tests wavelength and power levels. One or more of these tests may be performed by one or more modules of the test instrument.

[0036] Conventionally, the pluggable modules may run one or more of the same applications and threads to perform various network tests, and each module duplicates the entire network test application, which can waste system resources and battery power. For example, the base module comprises a hardware accelerated network test module to perform customer network testing and analysis. Hardware acceleration may be provided by a field programmable gate array (FPGA) or other similar hardware acceleration circuit that performs network testing and analysis for a network test. The base module may also include processors and memory. The base module is controlled by several layers of software including the hardware abstraction layer, system software layer and application layer. The application layer may run multiple software threads, which are further discussed below. The pluggable modules of the test instrument may also be hardware accelerated network test modules, and run additional copies of each of the above-described software layers and threads. This increases the system resource usage including usage of a central processing unit (CPU), memory, I/O and power.

[0037] According to an example of the present disclosure, the test instrument can utilize threads for a network test application running on different modules of the test instrument instead of duplicating the threads on each module, which conserves system resources of the test instrument. The threads are executed in containers of each of the modules. A container is an operating system-level virtualization or application-level virtualization over multiple network resources so that software applications can run in isolated user spaces called containers in any cloud or non-cloud environment. Individually, each container simulates a different software application and runs isolated processes by bundling related configuration files, libraries, and dependencies, but, collectively multiple containers share a common operating system kernel. A container is a fully functional and portable cloud or non-cloud computing environment surrounding the application and keeping it independent from other parallelly running environments. Containers are isolated from one another and bundle their own software, libraries, and configuration files, but they can communicate with each other through defined protocols. Docker™ and Kubernetes™ are some examples of containers that may be used in the test instrument.

[0038] Each container includes a namespace. A namespace is a declarative region that provides a scope to the identifiers, e.g., the names of types, functions, variables, threads, or other objects inside it. A namespace is commonly used to uniquely identify one or more names from other similar names of different objects which may be in a different namespace. The namespaces provided by the containers can be used to isolate the software layers and application threads and at the same time allow re-use by leveraging the overlay filesystem provided by the container to maintain a single image of the software in memory but use them in different containers.

[0039] In order to maintain a single image of the software for the test application in memory but use the threads for the network test application in different containers, an application name discovery and routing service (ANDR) is executed in each of these containers. An ANDR comprises code running in a container that performs various function described below, including application and thread registration, and command and control operations for instructing threads in different containers to perform operations for the network test application. The ANDRs can route command and control messages between various application threads running in different containers to perform operations of the network test application. Each ANDR maintains an ANDR database of applications and threads that are running inside each of the different containers, so each ANDR is aware of the applications and threads running in its container and other containers. The applications and threads are registered with the ANDRs using a unique ID, e.g., referred to as a domain. In an example, the unique ID is randomized and generated based on a network interface media access

control (MAC) address. The ANDRs running inside the containers discover each other using an ANDR discovery protocol at container startup. The application threads running in each container can then communicate with each other by appending the domain, such as application@domain, as the destination address in the command and control messages thus enabling automatic distributed and scalable processing of multiple hardware modules connected to the test instrument. By using the containers, the ANDRs and the ANDR databases, the test instrument can utilize threads of a network application running in different containers so each module does not need to load and execute separate instances of the entire test application. This reduces the system resource usage including processing, memory, I/O and power.

[0040] A container with an ANDR can be launched on a base module, and a container with an ANDR can be launched on each pluggable hardware test module connected to the test instrument. In an example, to launch a container, a container daemon is launched as a host process, which may be in response to normal operating system bootup. The container client can then be launched to create a container image on the module. When the container is launched, it spawns the ANDR and other application processes inside the container. The ANDR discovery and routing mechanism is also enabled which allows the routing of messages between applications in each of the namespaces as the networking is namespace constrained to the specific container.

[0041] When a network test is launched on a module, it may require execution of one or more network test applications and/or threads. The following describes by way of example a general flow of events, including threads that are launched, when a network test application is launched on a module. A User Interface (UI) thread renders a UI to collect test input parameters. An Input Validation thread validates the input. A Hardware Gating thread gates the input based on an event and/or an interrupt from a Hardware Abstraction Layer (HAL) thread. The HAL thread maintains a database of hardware events and communicates with the hardware. A Network Test and Analysis thread uses the input parameters to generate test templates. A System Download thread transfers the test templates to the hardware. A Latching thread periodically latches the results generated by the hardware. A Results Analysis thread performs the required analysis on the generated results. A Results Generation thread generates the results in the form of graphs, tables, and other formats. A Results Presentation thread renders the results in the UI. The above-described threads and workflow of events are generic and applicable to multiple different tests that can be run by the test instrument.

[0042] FIG. 1 shows, by way of example, a high-level architecture of containers **10a-c** including ANDRs a-c, threads, namespaces and domains, which may be provided in one or modules of a test instrument **100**. The containers **10a-c** may be hosted on different modules, e.g., a base module and/or one or more pluggable modules, of the test instrument **100**. ANDRs a-c are executed in containers **10a-c**, respectively. Each container has its own namespace, shown as namespaces A-C, and its own domain, shown as domains A-C. ANDRs a-c maintain communication with each other.

[0043] The threads discussed above are for a network test application. One or more of the threads running in different containers may be used by multiple instances of the same network test application running on one or modules of the test instrument **100**. A possible but not a complete distribution of the threads discussed above is shown in FIG. 1. For example, the UI Thread and Input Validation Thread are in Domain A; the Hardware Gating Thread and HAL Thread are in Domain B; and the Network Test Analysis Thread and System Download Thread are in Domain C. Each of these threads run the applications with the same name, and each of the applications in each of the domains registers with the ANDR in their domain, and the registered application information is shared among ANDRs in different domains as is further discussed below.

[0044] Each of the ANDRs a-c maintains an ANDR database that keeps track of the applications and threads running in the different containers and domains on the modules of the test instrument **100**. An example ANDR database format is as follows:

TABLE-US-00001 Test Application XXX Domain UI Thread A Input Validation Thread A

Hardware Gating Thread B HAL Thread B Network Test Analysis Thread C System Download Thread C

[0045] In this example, test application XXX is comprised of the threads shown above which happen to be running in domains A-C in containers **10a-c**. The ANDR database keeps track of which domains are executing which threads of the application. The ANDR database is searched to determine if a thread needed for an application is already running in a different domain, and the ANDR to an ANDR of another domain to utilize a thread running in the other domain. For example, as shown in FIG. 3 as is further described below, ANDR a checks the ANDR database to determine that another ANDR, i.e., ANDR b, is running the Hardware Gating Thread, and sends a command and control message to ANDR b which is forwarded by ANDR b to the Hardware Gating Thread to gate the hardware. Accordingly, the module running the threads in domain A does not need to launch the Hardware Gating Thread, which conserves hardware resources, including CPU cycles, memory, and battery power.

[0046] An ANDR message format is used for messages communicated between the ANDRs a-c. The ANDR message format includes the following fields: Unique Message ID; Source Application name registering with ANDR; ANDR name; Message type which could be cmd, async, or ack; and Message name which could be register, unregister, or app\_connected. The ANDR message format is as follows, whereby the message fields are delimited by colons: MessageId:application-name:andr-name:message-type:message-name.

[0047] An ANDR, such as each of ANDRs a-c, follow an application registration protocol to register the applications and threads running in the domain with the ANDR running in that domain. Then, the ANDRs can store the registration information in the ANDR database and share the information between the ANDRs, so each ANDR is aware of the applications and threads running in each domain. FIG. 2 shows the protocol that is followed to register an application, e.g. app1, running in Domain A with ANDR a. The protocol shown in FIG. 2 is as described below.

[0048] Unregistered app1 sends a register message to ANDR a in its domain. The message format is 23:app1:andrA:cmd:register. ANDR a sends ack message back to app1. The message format is 23:andrA:app1:ack:register. ANDR a sends app\_connected async message to all the already registered applications, such as apps 1-4. The message formats for the async messages are 0:andrA:app2:async:app\_connected app1; 0:andrA:app3:async:app\_connected app1; and 0:andrA:app4:async:app\_connected app1. Then, ANDR a shares the information for registered app1 with all the other ANDRs b-c. The shared information may include the registered application and the threads that are running for the registered application, if any, in the domain.

[0049] FIG. 3 shows a flowchart for launching a network test application for a network test, and describes command and control messages exchanged between ANDRs in different domains to run threads in different containers for the network test application. The command and control messages may include data to be operated on by a particular thread, such as user input to be validated or test parameters to be validated for hardware gating, etc. As shown in FIG. 3, an ANDR can check the ANDR database in its domain to determine if any other domains are running a thread that is needed to execute the test based on entries in the ANDR database if its domain is not running the thread. If so, the ANDR sends a command and control message to the appropriate ANDR in a different domain with input parameters. Then, the ANDR in the different domain receives the command and control message with input parameters and passes the input parameters to the thread in its domain to perform a function to execute the test. FIG. 3 is described below with respect to the example in FIG. 1 where the UI Thread and the Input Validation Thread are running in Domain A, the Hardware Gating Thread and HAL Thread are running in Domain B; and the Network Test Analysis Thread and the System Download Thread are running in Domain C. One or more of the messages described below with respect to FIG. 3 may be command and control messages, including the messages transmitted between ANDRs. Also, in an example, the test instrument **100** may have multiple modules running the same network test application. Instead of duplicating the

network test application on both modules, a single instance of the network test application is distributed across containers, and the ANDRs exchange command and control messages to utilize the threads in the different containers.

[0050] Referring to FIG. 3, at **301**, a network test is launched on the test instrument **100**. This may include a user selecting a test on the test instrument **100** to run. In an example, the test may be selected via a display or other interface on a base module but may be executed using a pluggable module and/or the base module. For example, the test may be a 400 Gigabit Ethernet (GbE) layer 1 optics test that can test 400G circuits and QSFPs. Other examples of tests may include OTDR, an RFC 2544/Y.1564 service activation test, and OTN test and other tests described herein. The network test application for the network test is launched in a container, such as container **10a**, and container **10a** includes the threads discussed above with respect to FIG. 1. In this example, container **10a** includes the UI thread and the Input Validation thread as shown in FIG. 1.

[0051] At **302**, the UI thread collects test input parameters. For example, assume the 400 Gigabit Ethernet (GbE) optics self test is selected to test a QSFP. Test configuration settings are input into the test instrument **100**, for example, by the user. For example, test duration, a FEC type (e.g., Reed-Solomon), a bit error rate (BER) type (e.g., pre-FEC or post-FEC) and a BER threshold are examples of configuration settings for 400 GbE QFSP testing. This information is collected and stored by the UI thread.

[0052] At **303**, the UI thread sends a message to ANDR a to validate the test input parameters by the Input Validation thread. At **304**, ANDR a checks the ANDR database in its domain, and determines an Input Validation thread is running in its domain in container **10a**, and ANDR a forwards the message to the Input Validation thread in container **10a**. At **305**, the Input Validation thread determines whether the test input parameters are valid or invalid. For example, Reed-Solomon is the proper FEC type for 400 GbE testing but if another FEC type is entered as a configuration setting, it can be rejected by the Input Validation thread.

[0053] At **306**, if the test input parameters, e.g., the configuration settings, are determined to be invalid, the test is indicated as failed. At **307**, if the input is determined to be valid, the Input Validation thread sends a message to ANDR a for hardware gating by a Hardware Gating thread.

[0054] In the next steps, the Hardware Gating thread and the HAL thread check if the test input parameters are compatible with the hardware, such as an FPGA, to perform the test and that the hardware is in the proper state to run the test. At **308**, ANDR a checks the ANDR database to determine if the Hardware Gating thread is running in a different domain, and routes the message to ANDR b. For example, ANDR a determines the Hardware Gating thread is running in domain B of container **10b**, and ANDR a routes the message to ANDR b, which forwards the message to the Hardware Gating thread running in container **10b**.

[0055] At **309**, the Hardware Gating thread gates the test parameter inputs and sends a message to ANDR b with the inputs to check with the HAL thread to determine whether the input is compatible with the hardware. At **310**, ANDR b checks the ANDR database in its domain, and determines the HAL thread is running in its domain in container **10b**, and forwards the message to the HAL thread in container **10b**. At **311**, the HAL thread determines if the input is compatible with the hardware. For example, the HAL thread determines whether the FPGA is compatible with a particular byte test pattern or determines whether the FPGA is configured to run the test.

[0056] If the input is determined to be incompatible, the test is indicated as failed (step **306**). At **312**, if the input is determined to be compatible, the Hardware Gating thread gates the inputs with the hardware, and sends a message to ANDR b to run a Network Test Analysis thread. At **313**, ANDR b checks the ANDR database and determines the Network Test Analysis thread is running in domain c (container **10c**), and routes the message to ANDR c. At **314**, ANDR c forwards the message to the Network Test Analysis thread is running in container **10c** and uses the input parameters to generate test templates.

[0057] At **315**, the Network Test Analysis thread sends a message to ANDR c to run a System



Download thread on the templates. At **316**, ANDR c forwards the message to the System Download thread running in the same container **10c**, and the System Download thread transfers the test templates to the hardware.

[0058] At **317**, a Latching thread periodically latches the test results generated by the hardware. The test results are stored in memory. At **318**, a Results Analysis thread performs the required analysis on the generated results. Examples of test results may include pass or fail for signal presence, optical signal level and whether a bit error rate exceeds a threshold. Also, optical power levels for transmitting and receiving can be determined. At **319**, a Results Generation thread generates the results, which may include graphs, tables, and other formats. At **320**, a Results Presentation thread renders the results in the UI of the test instrument **100**. Although not described, steps **317-319** include steps where an ANDR forwards a message to a thread in its container or the ANDR routes the message to an ANDR in another container similar as described above with respect to previous steps.

[0059] In general, as is described above, each ANDR checks its ANDR database to determine whether a needed thread is running in its container or another container. If the needed thread is running in its container, the ANDR forwards a message, which may include data inputs, to the thread in its container (i.e., the current container). If the needed thread is running in a different container, the ANDR forwards the message to the ANDR of the other container that is running the thread, so the thread does not need to be duplicated in the current container. If a thread is determined not to be running in the current container of the ANDR and not to be running in a different container, then the thread is spawned in the current container or another container, which may be based on resource usage.

[0060] FIG. **4** shows the initialization of the components of the ANDR by systemd, and FIG. **5** shows the initialization of a Docker™ client for running a network test application running inside a Docker™ container. Docker™ is one example of a type of container that may be used by the test instrument **100**. Other types of containers may be used in the test instrument **100**. In FIG. **4**, the Docker™ container daemon which provides the runtime, Docker™ socket and shim service layer for Docker™ is launched by running the dockerd containerd with parameters. Then, the Docker™ daemon is provided by launching the dockerd containerd. FIG. **5** shows the initialization of the network test application running inside a Docker™ container. Systemd launches the recordserv service. As part of this, a script is run, which reads solution records. If it finds the requisite record, it launches the Docker™ client with the Docker™ image containing the network test application. The network test application running inside the Docker™ client includes the ANDR. UI and other embedded applications are launched which communicate with the module hardware to run the network test application based on the configuration provided and provides the test results.

[0061] FIG. **6** shows a sequence when a network test application is launched on the test instrument **100**, such as by a user selecting, through a UI, a test to be performed by the test instrument **100**. The test application for the test running inside the container communicates with the various threads to launch the test application based on resource availability. As part of this, the hardware files are downloaded into the module hardware and the test configuration is specified so that the test can be launched based on the specified configuration. As the hardware latches the results, they are read by the application and displayed to the user.

[0062] FIG. **7** illustrates a control groups (cgroups) hierarchy for a CPU, memory, and block I/O that can be used for the containers, and which are in one or more of the modules of the test instrument **100**. Cgroups, are an operating system, e.g., Linux, kernel feature which allow processes to be organized into hierarchical groups whose usage of various types of resources can then be limited and monitored. The kernel's cgroup interface is provided through a pseudo-filesystem called cgroupfs. Grouping is implemented in the core cgroup kernel code, while resource tracking and limits are implemented in a set of per-resource-type subsystems (memory, CPU, and so on). A cgroup is a collection of processes that are bound to a set of limits or parameters defined via the

cgroup filesystem. A subsystem is a kernel component that modifies the behavior of the processes in a cgroup. Various subsystems have been implemented, making it possible to do things such as limiting the amount of CPU time and memory available to a cgroup, accounting for the CPU time used by a cgroup, and freezing and resuming execution of the processes in a cgroup. Subsystems are sometimes also known as resource controllers (or simply, controllers).

[0063] The cgroups for a controller are arranged in a hierarchy. This hierarchy is defined by creating, removing, and renaming subdirectories within the cgroup filesystem. At each level of the hierarchy, attributes (e.g., limits) can be defined. The limits, control, and accounting provided by cgroups generally have effect throughout the subhierarchy underneath the cgroup where the attributes are defined. Thus, for example, the limits placed on a cgroup at a higher level in the hierarchy cannot be exceeded by descendant cgroups.

[0064] The pie chart shown in FIG. 7 shows the three cgroups on a Linux machine. The three cgroups are System, User and Machine. Each of these cgroups is also known as a “slice”. A slice can have child slices, as is seen by the System slice in the diagram. All of these slices always add up to 100% of the total resources for a specific controller (CPU, Memory, etc.).

[0065] As shown the three top level slices (system, user and machine) are each granted equal CPU time with each other but this only happens once the system ends up under load. If a single process in the User slice wants 100% and nothing else does, this process will be granted that CPU time.

[0066] The three top level slices (system, user and machine) all have specific workloads that end up as sub-slices. System is where daemons and services are placed. User is where user sessions are placed. Each user gets a single slice under the main group. This prevents stealing of resources than they are allowed. Machine is the hardware.

[0067] One method of controlling resource usage is with the concept of “shares”. Shares are a relative value and the actual numbers only matter when compared to other values in the same cgroup. By default, slices are set to a value of 1024. So, in the system slice discussed above, httpd, sshd, crond and gdm are each set to use 1024 CPU shares. System, User and Machine are each set to 1024 themselves.

[0068] FIG. 8 shows that a container may be a combination of namespaces and control groups.

[0069] FIG. 9 shows that a cgroup for a container can be used to control usage of CPU, memory, and block I/O.

[0070] Containers can run on a distributed service architecture. A multi-core distributed service architecture is illustrated in FIG. 10. Each Node is a core of a multi-core processor. The processes and threads in the system are distributed across the different cores based on standard scheduling policies which doesn't normally consider the specific requirements of the services. The service state flow for creating, scheduling and terminating a process is illustrated in FIG. 11. By grouping related threads of a service into a control group using containers the I-cache and D-cache performance can be increased by leveraging spatial and temporal coherence.

[0071] As was mentioned above, the test instrument **100** may be comprised of multiple modules that allows it to scale to accommodate new testing requirements as needed. A module comprises hardware including a processing circuit (also referred to as a processor) and memory, and software can be loaded on the module. One or more of the modules may be removably connected to the test instrument **100**. A module may include a hardware-based acceleration module for performing network test operations. The hardware-based acceleration module may include a FPGA or some other type of processing circuit to perform network testing functions. An example of a module is a 400G module with PAM-4 400G, 200G, 100G testing.

[0072] A description is now provided of some examples of modules for the test instrument **100** that can perform various tests. According to an example, the test instrument **100** may include various removably connectable Solution Modules, various removably connectable Expansion Modules, and various integrated modules that may be factory installed. According to an example, the test instrument **100** may include a Base Module to provide core processing functionality. The test

instrument **100** may also include other modules, such as a 400G module, a User Interface Module, a Battery Module to supply portable power, and other modules that are further discussed below. Examples of the modules are described below but the test instrument **100** is not limited to those modules.

[0073] The test instrument **100** may include a Base Module, to support a common platform. The Base Module includes interfaces ready to connect to various other Solution Modules and/or Expansion Modules as needed to provide the ability to perform desired tests. The Base Module may communicate with a synchronizing server or workstation to automatically obtain configuration settings, software options, updates, and registration.

[0074] The test instrument **100** may include a pluggable 400G module and/or a pluggable 100G module. The 400G module can perform PAM-4 400G, 200G, 100G testing. The 100G module supports independent dual tests for any protocol from T1/E1 to OTU4 including intermediate rates like 10G and 25G rates. The modules may be stacked. For example, multiple 400G modules can be connected to the base module to test a plurality of 400G circuits simultaneously.

[0075] The test instrument **100** may include a module for performing fiber inspection and testing. Standards bodies have established acceptance criteria for the quality and cleanliness of fiber and fiber connector end faces. Fiber inspection probes and fiber optic inspection scopes are required to maintain fiber in accordance with these standards and specifications. For example, a single particle mated into the core of a fiber can cause significant back reflection, insertion loss, and equipment damage. Contaminated or “dirty” fiber is a cause of fiber optic network degradation. As a result, proactive fiber optic inspection programs support the deployment of large-scale fiber optic network and fiber optic testing initiatives to ensure reliable, high-quality, high-speed, and high-capacity broadband services. Fiber inspection probes and fiber optic inspection scopes (also known as fiber microscopes) integrate with the test instrument to determine the cleanliness of fiber connections during network installation.

[0076] Industry associations maintain guidance for fiber optic inspection and fiber optic cleaning practices and procedures, including BICSI and the Fiber Optic Association. BICSI is a professional association supporting the advancement of the information and communications technology profession. The Fiber Optic Association is an international society of professionals that creates industry standards for training and certifying fiber optic technicians. The International Electrotechnical Commission (IEC) created IEC 61300-3-35, which specifies Pass/Fail requirements for connector end-face quality and network performance throughout the fiber optic life cycle.

[0077] The test instrument **100** may include a module for performing QSFP and SFP Monitoring. QSFPs are Quad Small Form-factor Pluggable units that support optics functionality. QSFPs are available in different variants, covering a wide range of applications, and include: SR-4, LR-4, etc.; 4×10G (QSFP+) or 4×25G (QSFP28).

[0078] The test instrument **100** may include a removably connectable OTDR Module for optical time domain reflectometer testing. OTDR testing is fiber optic testing for the characterization of optical networks that support telecommunications. The purpose of OTDR testing is to detect, locate, and measure elements at any location on a fiber optic link. An OTDR Module may require access to only one end of a link and acts like a one-dimensional radar system. By providing pictorial trace signatures of the fibers under test, it is possible to obtain a graphical representation of an entire fiber optic link. In other words, the OTDR Module creates a virtual “picture” of a fiber optic cable route. The analyzed data can provide insight into the integrity of the fibers, as well as any passive optical component such as the connectors, splices, splitters, and multiplexers along the cable path. The data can be recalled as needed to evaluate the degradation of the same cable over time. The OTDR module is capable of troubleshooting fiber optic cable failures by locating a distance to fault (DTF) and identifying the type of fault, such as breaks, bends, bad connectors, and portions having excessive loss.

[0079] The OTDR module injects pulsed light energy (pulsed optical power), generated by a laser diode, into one end of an optical fiber. A photodiode measures over time the returning light energy or optical power (reflected and scattered back) and converts it into an electrical value. Once amplified and sampled, the value may be graphically displayed on a screen. The OTDR Module measures and shows the location and loss of passive optical network elements which are called OTDR trace “events”. The location or distance to each event is calculated from the round-trip time of the light pulse traveling along the fiber. The loss is calculated from the amplitude value of the returned signal or optical power (also known as a backscattering effect).

[0080] The test instrument **100** may include a removably connectable Optical Spectrum Analyzer (OSA) Module for optical spectrum analyzer testing by way of a coarse wavelength division multiplexer (CWDM) analyzer. Historically, large and expensive optical spectrum analyzers (OSA) were used to precisely test wavelength and power levels in CWDM networks, and optical channel checkers were used to verify optical channel presence. The OSA Module offers the functionality and speed of a conventional OSA in a handheld form factor.

[0081] Fiber optic cable lengths may be measured in kilometers with varying equipment along a backhaul signal path. The International Telecommunication Union Telecommunication Standardization Sector (ITU-T) coordinates standards for telecommunications. ITU-T G.695 specifies transmitter/multiplexer characteristics at one end of a CWDM link and de-multiplexer/receiver characteristics at the other end. ITU-T G.694.2 specifies a spectral grid for CWDM applications with 18 channels from 1271 to 1611 nm, with 20 nm channel spacing. The OSA Module may verify optical interface parameters according to the above standards, such as Tx output power, Rx input power, and central wavelengths.

[0082] In CWDM networks, transmitter lasers are typically not equipped with a cooling system, thus temperature variations can cause a drift of the central wavelength and the power level. The OSA Module can verify possible wavelength shifts or power loss. Transmitters with a wavelength offset can create additional attenuation in the multiplexers and de-multiplexers. When test access points are available, the OSA Module may determine a wavelength's presence and its associated power level to verify that all transmitted wavelengths have been correctly multiplexed without excess power loss on one of the channels. A wavelength drift in a transmitter can create power drift which may cause bit errors. The OSA Module may monitor and record the evolution of channel power and wavelength over time. The OSA Module may include Small Form-factor Pluggable (SFP) transceivers to test a link between a head end and a tail end when a system transceiver is unavailable.

[0083] The test instrument **100** may include a battery module and other modules for performing network testing and/or cell site installation tests.

[0084] FIG. **12A** illustrates a perspective view of test instrument **100** including Base Module **106** and I/O device **102** (which may be removably connected), according to an example of the present disclosure. Test instrument **100** may be a modular hand-held tool comprising removably connectable field replaceable Modules for cell site installation, testing, measurement, and maintenance. According to an example, test instrument **100** includes removably connectable I/O device **102**, and a removably connectable Base Module **106**. According to an example, I/O device **102** includes a display **103** that provides user control and information. According to an example, display **103** may be a touch screen, e.g., liquid crystal display (LCD) touchscreen. The test instrument **100** provides user information including: a listing of jobs, a listing of reports to be compiled, a compilation of executed test results in a test report or test reports, and an interface control with a work station or server, described in greater detail below. Base Module **106** provides hardware, software and firmware, described in greater detail below, to control test instrument **100**.

[0085] According to the illustrated example of FIG. **12A**, ventilation ports **105** are provided to the outer structure of Base Module **106** to facilitate internal cooling of components by way of an internal cooling unit. Loudspeaker **107** provides audio information. Base Module **106** provides a

structural base for test instrument **100**, and includes support structures **108** for attachment of a support strap (not shown). According to an example, support structures **108** are metal pins permanently secured to the structure of Base Module **106**. I/O device **102** includes elastomeric bumpers **112** to provide impact protection. Likewise, Base Module **106** includes elastomeric members **182** which may act as bumpers.

[0086] According to an example, test instrument **100** may be configured in a variety of assemblies with a plurality of different removably connectable Modules to support workflow and project specifications. According to the illustrated example of FIG. **12A**, test instrument **100** includes first expansion module **110** removably connected to the bottom of Base Module **106**.

[0087] FIG. **12B** illustrates a back side view of Base Module **106**, according to an example. In an example, Base Module **106** includes a plurality of modular elements used for cell site installation, testing, measurement, and maintenance. According to an example, Base Module **106** includes PM-DL module **120**, also known as a power meter/datalink optical module. PM-DL module **120** and other modules described herein may be factory installed with Base Module **106** or one or more modules may be attached to Base Module **106** by a user. In an example, PM-DL module **120** is secured by way of connection members **122**. Connection members **122** provide integration of PM-DL **120** and mechanical structural support for an optical connection. PM-DL module **120** includes power meter port **123** and TS-PC port **124**, also known as a Talkset-Datalink port. Power meter port **123** is used to determine optical power of a fiber under test. TS-PC port **124** is used to communicate voice or data with another device along an optical fiber.

[0088] Power meter port **123** and TS-PC port **124** may be optical Universal Push Pull (UPP) connectors, compatible with all diameter 2.5 mm connectors (fiber connector (FC), subscriber connector (SC), straight tip (ST) connector, Deutsches Institut für Normung (DIN) connector, E2000, etc.). An FC connector is a single mode connector using a 2.5 mm ferrule according to Telecommunications Industry Association (TIA) connector intermateability standard FOCIS-4 (TIA-604-4). An SC connector is a snap-in connector using a 2.5 mm ferrule according to TIA connector intermateability standard FOCIS-3 (TIA-604-3). An ST connector is a spring-loaded optical connector that has a bayonet mount and a long cylindrical 2.5 mm ceramic ferrule to hold the fiber according to TIA connector intermateability standard FOCIS-2 (TIA-604-2). A DIN connector is a fiber connector having a 2.5 mm ferrule and a screw type connector according to International Electrotechnical Commission standard IEC 61754-3. An E-2000 connector is a fiber connector having a 2.5 mm ferrule and a snap coupling and a light and dust cap according to IEC standard 61754-15.

[0089] According to an example, Base Module **106** also includes VFL module **126**, also known as a Visual Fault Locator module, to provide detection of a visual fault location. VFL module **126** includes VFL optical port **127** and port **128**. According to an example, VFL optical port **127** is a UPP connector. A VFL test uses brightly visible light to check patch cords for defects and verify continuity. According to examples, combinations of PM-DL module **120** and VFL module **126** may provide various functions including: 1. Power Meter-Only; 2. Talkset and Datalink; 3. Talkset and Datalink & Power Meter; 4. VFL-Only; and 5. VFL & Power Meter.

[0090] According to an example, Base Module **106** includes several additional inputs and control interfaces as follows. Reset button **130** provides a hard reset of test instrument **100**. Reset button **130** may be depressed with a small object, such as an extended paperclip. Micro-SD port **132** provides removable storage to test instrument **100** by accepting a micro-SD card. The micro-SD card may provide memory for storing cell site data, predetermined setup configurations, test results, and compiled reports. USB-C port **134** provides an interface to test instrument **100** according to the USB-C standard. USB-C port **134** also provides a debug-serial-port to support testing and troubleshooting of test instrument **100**. An audio interface, and/or headset may be multiplexed with USB-C port **134** by way of an external adapter, such as a USB-C to 3 mm adapter. A pair of USB-A Interfaces **136a** and **136b** provides support for connection of USB 2.0/3.0 peripherals, such as an

external fiber microscope, set forth in greater detail below.

[0091] Audio jack **138** provides a direct audio interface by accepting a 3 mm male plug. Ethernet port **140** is RJ-45 jack to provide 10/100/1000-BaseT Ethernet management. On/Off switch **142** is configured to turn test instrument **100** on and off. DC-input **144** is configured to receive DC power for test instrument **100** from an external power supply. In addition, an internal smart battery module may provide DC power. Although not illustrated in FIG. **12B**, a mini-USB port may also be provided. Internal to Base Module **106** is a wireless network module to support wireless network communication, such as at 2.4 GHz and 5 GHz, and a Bluetooth module to support Bluetooth communication with an external device, such as a Bluetooth audio headset.

[0092] FIG. **12C** illustrates a top view of Base Module **106**, according to an example of the present disclosure. Base Module **106** includes a plurality of through holes **176** to mate with corresponding protrusions **174** in the housing of I/O device **102**. Base Module **106** provides electrical power and communication to I/O device **102** or other modules, including Solution Modules and Expansion Modules, by way of base module backplane interface **170**. According to an example, base module backplane interface **170** is a 140-pin connector having 0.8 mm pitch Gold-Fingers. Other types of connectors may be used.

[0093] FIG. **12D** illustrates a bottom view of Base Module **106**, according to an example of the present disclosure. Base Module **106** includes a plurality of through holes **176** to receive a plurality of connection members **150** to removably secure Base Module **106** to I/O device **102**. If another Solution Module is removably inserted between Base Module **106** and I/O device **102**, connection members **150** pass through structurally defined holes in the inserted Solution Module before being received into I/O device **102**. According to an example, connection members **150** are machine screws having a hexagonal head. According to an example, connection tool **152** is disposed within Base Module **106** to support field replacement of different removably connectable Solution Modules (attachable to a top side of Base Module **106**). According to an example, connection tool **152** is an Allen wrench having a hexagonal head to mate with connection members **150**. Base Module **106** includes a plurality of access panels, such as access panels **154** and **156** to support factory installation of various internal modules, such as the wireless network module or Bluetooth module.

[0094] Base Module **106** includes first expansion interface **158** and second expansion interface **160** to provide electrical communication and power to a plurality of different Expansion Modules. According to an example, first expansion interface **158** and second expansion interface **160** are 140 pin connectors having 0.8 mm pitch Gold-Fingers. According to an example, the bottom of Base Module **106** includes recesses to receive corresponding cleats from Expansion Modules, such as cleats **188** shown in FIG. **12E** of expansion modules **110** and **111**. Threaded bushings **192** then receive structural members, which pass through holes in the Expansion Modules to be received therein.

[0095] FIG. **12E** illustrates an exploded perspective view of test instrument **100** including I/O device **102**, Base Module **106**, and expansion modules **110** and **111**, according to an example of the present disclosure. An optional screen cover **104** may be removably attached to the housing of I/O device **102** to provide protection to display **103**. Base Module **106** is removably connected to I/O device **102** by a plurality of connection members **150**. According to an example, I/O device **102** includes a plurality of protrusions **174** that are configured to be received within through-holes **176** defined by the structural housing of Base Module **106**. Connection members **150** pass through holes **176** and are removably received within protrusions **174** to create an integrated modular test instrument **100**. As illustrated, elastomeric members **182** are disposed about the corners of Base Module **106** to provide impact protection.

[0096] According to an example, first expansion module **110** has structure defining holes **178** and expansion module **111** has structure defining holes **180**. Connection members **190** pass through holes **178** and **180** and are received within threaded bushings **192** of Base Module **106**. Cleats **188**

of expansion modules **110** and **111** are received within recesses **177** in the bottom of Base Module **106**.

[0097] First expansion module **110** includes expansion interface **184** to communicate power and control signals with Base Module **106**. Likewise, expansion module **111** includes expansion interface **186** to communicate power and control signals. According to an example, expansion interfaces **184** and **186** are 140 pin connectors having 0.8 mm pitch Gold-Fingers to mate with first and second expansion interfaces **158**, **160** in Base Module **106**. According to an example, expansion modules **110** and **111** are field replaceable. For example, the expansion modules may include one or more 400G and 100G modules. According to an example, either of expansion modules **110** or **111** may be a smart battery module. According to an example, either of expansion modules **110** or **111** may be a spacer module that does not contain internal components or a battery.

[0098] FIG. **12F** illustrates an exploded perspective view of test instrument **100** including a removably connected module **194**, according to an example of the present disclosure. Upon integration of module **194**, Base Module **106** provides electrical power and communication to module **194** by base module backplane interface **170**. Likewise, module **194** provides electrical power and communication to I/O device **102** by way of top solution interface **196**. Module **194** also includes a bottom solution interface (not shown) connectable to base module backplane interface **170**, described in greater detail below. According to another example, a second module may be optionally disposed between module **194** and Base Module **106**, described in greater detail below. The base module backplane interface **170** connects power and communication (e.g., carrying data) busses of the Base Module **106** to modules connected to the Base Module **106** via base module backplane interface **170** or other interfaces. The backplane interface **170** is also connected to a memory and processor of a module.

[0099] Module **194** has a similar housing and form factor to Base Module **106** to provide integration between I/O device **102** and Base Module **106**. Module **194** includes a plurality of through holes **198** to mate with corresponding protrusions **174** in the housing of I/O device **102**. Module **194** provides electrical power and communication to I/O device **102** by way of top solution interface **196**. According to an example, top solution interface **196** is a 140-pin connector having 0.8 mm pitch Gold-Fingers. Module **194** also provides a structural base for test instrument **100**, and includes additional support structures for attachment of a support strap (not shown). Module **194** is removably connected to I/O device **102** by connection members **150**. As illustrated, Module **194** also includes elastomeric bumpers **182** for impact protection.

[0100] FIG. **13** illustrates a perspective view of removably connectable smart battery module **200** in the form of an expansion module, such as first expansion module **110**, according to an example of the present disclosure. Smart battery module **200** includes a battery **202** removably disposed therein, and secured by battery door **204**. Internal circuitry is included within smart battery module **200** to regulate smart charging of battery **202** and to ensure that power is supplied to Base Module **106** in a uniform manner. Smart battery module **200** provides power and communication with Base Module **106** by way of expansion interface **206**. According to an example, expansion interface **206** is a 140-pin connector having 0.8 mm pitch Gold-Fingers. **208** may be bumpers for protection.

[0101] FIG. **14A** illustrates a high-level system diagram of Base Module **106** and I/O device **102**, according to an example of the present disclosure. Base Module **106** includes system board **702** with interfaces to removably connect to various Solution Modules and Expansion Modules to form test instrument **100**. System board **702** removably connects to I/O device **102**, which houses and supports display **103**. According to an example, I/O device **102** is embodied in a modular housing, which is removably connectable to Base Module **106**. According to an example, display **103** is disposed within I/O device **102** and a GUI may be generated on the display **103** to provide user control of test instrument **100** for testing and measurement. The modular housing of I/O device **102** permits both field replaceability and connection of various additional Solution Modules. According to an example, Base Module **106** is on the order of 10" wide to permit hand carry by a field

technician.

[0102] System board **702** includes a control module **704**. According to an example, Control module **704** includes processor **705** and memory **707**. According to an example, processor **705** may include a programmable and replaceable processor module/card used in a test instrument system where pluggable/upgradable/flexible processor selection is desired. According to an example, processor **705** may be a multi-core, programmable, processor. According to an example memory **707** may be a 12CV EEPROM. Processor **705** processes software instructions stored in memory **707**.

[0103] According to an example, control module **704** facilitates a flexible processor choice for processor **705** such as an iMX6 or iMX8 processor from NXP semiconductor or other processor. Control module **704** may be a SMARC control module based on SMARC Version 2.0, and capable of supplying up to 15 W (5V/3A) to processor **705**. SMARC is a versatile small form factor computer Module definition. SMARC is essentially a replaceable processor module/card used in a system where pluggable/upgradable/flexible processor selection is desired. SMARC is a specification published by the Standardization Group for Embedded Technologies for computer-on-modules (i.e., COMs). SMARC Computer-on-Modules are specifically designed for the development of extremely compact low-power systems. SMARC modules can also be fitted with other low-power System-on-Chip (SoC) architectures, like, for example, ones based on x86 SoCs.

[0104] System board **702** includes base module SHIM **706**, which is a Software/Hardware Interface for Multi-Many-core (SHIM) interface, such as set forth in 2804-2019—IEEE Standard for Software-Hardware Interface for Multi-Many-Core. Base module SHIM **706** provides an architecture to support connection to a plurality of additional modules. Base module SHIM **706** connects to PM-DL module **120** and VFL module **126** with base module bus **715** through with base module interface **709**. Base module SHIM **706** connects to expansion interfaces **158** and **160** with expansion bus **713**. Base module SHIM **706** connects to base module backplane interface **170** through base module backplane **742**. According to an example, expansion interfaces **158** and **160** are 140 pin connectors having 0.8 mm pitch Gold-Fingers to electrically mate with a plurality of different modules. Base module SHIM **706** connects to power and interface circuits **708** to distribute power to connected modules through base module bus **715** and expansion bus **713**.

[0105] According to an example, I/O device **102** is removably connectable to Base Module **106**. I/O device **102** includes a display **103** that provides user control and user information, a listing of predetermined tests to be executed (i.e., a predetermined test plan), a listing of reports to be compiled, a compilation of executed test results in test reports, and interface control for communication with a work station or server. I/O device **102** includes an I/O backplane **751** that connects to base module backplane **742** of Base Module **106** at backplane interface junction **744**. I/O backplane interface **746** forms part of I/O device **102** and base module backplane interface **170** forms part of Base Module **106**. Together, I/O backplane interface **746** and base module backplane interface **170** form junction backplane interface junction **744**. The designation of PREV and NEXT provide a reference for connectivity of various modules in various configurations to base module backplane **742** in the various FIG.s.

[0106] According to an example, I/O device **102** is contained in a removable modular housing. In other words, display **103** functions as a special Solution Module. This permits both field replaceability and access within the platform to insert additional Solution Modules. According to an embodiment, display **103** supports a 1280×800 resolution with multi-touch capacitive interface capability. According to an example, a screen size on the order of 10" diagonal size is provided. According to another example, a screen size on the order of 8" diagonal size is provided. According to an example, display **103** is backlit to provide readable brightness in an outdoor environment.

[0107] According to an example, power and interface circuits **708** receive power from internal smart battery module **716** by way of smart battery interface **717**. According to an example, smart battery module **716** includes a dedicated battery internal to the structure of the Base Module **106**. The dedicated internal battery is field replaceable and is also rechargeable via power and interface



circuits **708**. The power and interface circuits **708** may also receive power by way of DC input **144**. Power and interface circuits **708** may also receive power by way of an Expansion Module containing a smart battery. Operation of Base Module **106** is initiated or turned off by way of On/Off switch **142**. Accordingly, the internal battery within smart battery module **716** may be recharged when DC power is supplied by way of DC input **144**. The internal circuitry of Base Module **106** is cooled by cooling unit **722**, which may include a fan, a heat sink, a temperature sensor and/or combination thereof. According to an example, control of a fan within cooling unit **722** is provided by way of a temperature sensor that provides a temperature indication signal to Control module **704**, which in turn controls operation of the fan.

[0108] Reset button **724** provides a hard reset of Base Module **106**. Reset button **130** may be depressed with a small object, such as an extended paperclip. SD port **132** provides removable storage to Base Module **106** by receiving a removable micro-SD card **726**. The micro-SD card may provide memory for storing customer data, setup configurations, reports, and test results. A pair of USB ports **136a** and **136b** provides support for connection of USB 2.0/3.0 peripherals. USB-C port **134** provides a debug-serial-port to support testing and trouble-shooting of Base Module **106**, and an external audio interface (and/or headset). The external headset may be multiplexed with USB-C port **134** by way of an external adapter, such as a USB-C to 3 mm adapter. Audio jack **138** may provide a direct audio interface by accepting a 3 mm male plug. Ethernet port **140** is an RJ-45 jack to provide 10/100/1000-BaseT Ethernet management.

[0109] Wireless network module **710** provides a wireless network interface to Base Module **106** by way of communication between antenna **711** and Control module **704**. Bluetooth module **712** provides a Bluetooth interface to Base Module **106** by way of communication between antenna **711** and Control module **704**. According to an example, wireless network module **710** and Bluetooth module **712** form the same module. According to an example, several wireless options, such as Wi-Fi and Bluetooth configuration choices, are supported.

[0110] According to an example, wireless network module **710** or Bluetooth module **712** may be accessed separately after Base Module **106** is fully assembled and enclosed. This permits a factory-option of wireless network or Bluetooth to meet varying end user requirements. Although not shown, a Wireless-Module access ‘door’ may be provided with a special fastener, different from the connection members set forth above, to discourage access without a special-tool. According to an example, three internal Wi-Fi antennas of antennas **711** may be mounted within Base Module **106**, and optionally one internal Bluetooth antenna.

[0111] According to an example, Base Module **106** includes optional PM-DL module **120**, also known as a power meter/datalink optical sub module. According to an example, the PM-DL **120** connects to base module SHIM **706** through base module bus **715** and base module interface **709** and is factory installed into the Base Module **106**. PM-DL **120** includes power meter port **123** and Talkset-Datalink (TS-PC) port **124**. TS-PC port **124** is an optical connector that is UPP, which is compatible with all diameter 2.5 mm connectors (FC, SC, ST, DIN, E2000, etc.). According to an example, Base Module **106** also includes VFL module **126** to provide visual fault location. VFL module **126** connects to base module SHIM **706** through base module bus **715** and base module interface **709**. VFL module **126** includes a VFL optical port **127**. According to an example, the VFL optical port is an optical connector that is UPP, which is compatible with all diameter 2.5 mm connectors (FC, SC, ST, DIN, E2000, etc.). According to an example, optional VFL module **126** is factory installed into the Base Module **106**. According to examples, various combinations of power meter module **300** (included in PM-DL module **120**), talkset datalink module **320** (included in PM-DL module **120**), and visual fault locator module **126** are available to support: 1. Power Meter only; 2. Talkset and Datalink only; 3. Talkset and Datalink & Power Meter; 4. VFL only; and 5. VFL & Power Meter. According to an example, Base Module **106** also includes factory installed internal modules, supporting the following options: Talkset & Power Meter; Power Meter & VFL; VFL only; and Power Meter only.

[0112] According to an example, cooling unit **722** includes an integrated fan with a speed control to manage internal temperature of the system board **702**, Control module **704**, wireless network module **710**, and smart battery module **716**. Base Module **106** power consumption may be affected by choice of processor module, contained within Control module **704**. According to an example, Base Module **106** has a power budget on the order of 15 W including display **103** at full brightness (exclusive of extra power required for battery charging). According to an example, system power supplied to Base Module **106** from DC input **144** is a maximum of 15A\*26V (390 W). According to an example, Base Module **106** includes “Apple-MFI” circuitry for compatibility with “Apple” products, and all USB ports are capable of supplying 0.5A DC at 5V to external USB Load. According to an example, an Audio/Headset may be muxed with USB-C port and accommodated using an adapter (i.e., USB-C to 3 mm). According to an example, a platform loudspeaker (not shown) is provided within Base Module **106** or I/O device **102** to provide audio without requirement for connection of an audio headset. According to an example, DC power may be applied to DC input **144** by way of a 160 W AC-DC Power Brick.

[0113] According to an example, internal smart battery module **716** includes a single battery, which is field replaceable. Battery access is provided without need to disassemble/remove any of its Modules. According to an example, the battery compartment of Base Module **106** may be compatible with Inspired-Energy NH2054VV34. According to an example the primary battery may be 14.4V, 6.8A-hr, 98 Wh, 8A capable NH2054VV34, having a run time on the order of four hours. According to another example, dual battery support may be provided by connection of another smart battery to expansion interface **158** or expansion interface **160**. An additional smart battery may provide additional power to support module scalability.

[0114] According to an example, Base Module **106** supports expansion modules **110** and **111** (e.g., OTDR, 400G, 100G, etc.) for connection at expansion interfaces **158** and **160**, and full size Solution Modules for connection at base module backplane interface **170**. According to an example, Base Module **106** may support up to four removably connectable modules, namely two removably connectable Expansion Modules by way of hardware interfaces, such as expansion interfaces **158** and **160**, and two full-size removably connectable Solution Modules by way of a hardware interface, such as base module backplane interface **170**.

[0115] FIG. **14B** illustrates a high-level system architectural diagram of Base Module **106** removably connected to module **194**, second solution module **195**, and I/O device **102**, according to an example of the present disclosure. Solution Modules **194** and **195**, shown in dashed box **754**, are removably connectable between I/O device **102** and Base Module **106** to form an integrated test instrument **100**. According to an example, either of solution modules **194** or **195** may be a Spectrum Analyzer and Common Public Radio Interface Module. Base Module **106** connects to expansion module **110** at first expansion interface **158** and second expansion module **111** at second expansion interface **160**. According to an example, Base Module **106** maintains a small to mid-range, hand held form factor.

[0116] According to the illustrated example of FIG. **14B**, module **194** includes a backplane **764** connected to top solution interface **196**, designated as NEXT, and a bottom solution interface **774**, designated as PREV. Top solution interface **196** is disposed on a top side of module **194** for connection to an interface disposed on the bottom side of an adjacent Solution Module, such as I/O backplane interface **746** of I/O device **102**. Bottom solution interface **774** is disposed on a bottom side of module **194** for connection to an interface disposed on a top side of an adjacent Solution Module, such as top solution interface **776** of second solution module **195**. According to an example of the test instrument **100** with module **194** included as a single solution module (i.e., without second solution module **195**), bottom solution interface **774** connects to base module backplane interface **170**.

[0117] Second solution module **195** includes a backplane **766** connected to top solution interface **776**, designated as NEXT, and a bottom solution interface **778**, designated as PREV. Top solution

interface **776** is disposed on a top side of second solution module **195** for connection to an interface disposed on the bottom side of an adjacent Solution Module, such as bottom solution interface **774** of module **194**. Bottom solution interface **778** is disposed on a bottom side of second solution module **195** for connection to an interface disposed on a top side of an adjacent Solution Module, such as backplane interface **170** of Base Module **106**. According to an example of the test instrument **100** with module **194** and second solution module **195**, base module backplane **742** is connected to backplane **766** of second solution module **195**, backplane **764** of module **194**, and backplane **751** of I/O device **102**.

[0118] According to FIG. **14B**, module **194** and second solution module **195** include backplanes. Either module **194** or second solution module **195** may support a single internal module configuration or a dual internal module configuration.

[0119] What has been described and illustrated herein is an example of the disclosure along with some of its variations. The terms, descriptions and figures used herein are set forth by way of illustration only and are not meant as limitations. Many variations are possible within the scope of the disclosure, which is intended to be defined by the following claims and their equivalents in which all terms are meant in their broadest reasonable sense unless otherwise indicated.

## Claims

1. A test instrument to execute a network test application to test an optical fiber network, the test instrument comprising: a plurality of containers comprising threads to perform operations of the network test application, each container comprising one of the threads to perform one of the operations of the network test application, an application name discovery and routing service (ANDR), and an ANDR database, wherein the ANDR of each container maintains the ANDR database of the container, and the ANDR database of each container includes entries that describe the threads in all of the plurality of containers, and wherein the ANDRs of the plurality of containers send command and control messages to each other to utilize at least one of the threads running in another container based on at least one of the entries in the ANDR databases.
2. The test instrument of claim 1, wherein the ANDR of a particular container determines whether a specific thread of the threads for the network test application is running in a different container based on one of the entries in the ANDR database of the particular container, and in response to determining that the specific thread is running in the different container, the ANDR of the particular container sends a command and control message of the command and control messages to the ANDR of the different container to run the specific thread based on input parameters provided in the command and control message.
3. The test instrument of claim 2, wherein in response to determining that the specific thread is not running in the different container, the ANDR of the particular container runs the specific thread in the particular container.
4. The test instrument of claim 1, wherein each ANDR registers network test applications and threads for the network test applications running in its container and other containers responsive to receiving register messages from the network test applications or other ANDRs.
5. The test instrument of claim 1, wherein each ANDR sends a message to another ANDR to identify new threads after startup of the container that comprises the ANDR.
6. The test instrument of claim 1, wherein the ANDRs discover each other using an ANDR discovery protocol at container startup.
7. The test instrument of claim 1, wherein each of the command and control messages comprise a destination address including a unique domain name of the ANDR of a receiving container to receive the command and control message.
8. The test instrument of claim 1, wherein each container of the plurality of containers is contained in one of a base module and at least one removable module attached to the base module.

- 9.** A network test instrument to test a network, the network test instrument comprising: a first container comprising a first thread to perform a first operation of a network test application, a first namespace, a first application name discovery and routing service (ANDR), and a first ANDR database; and a second container comprising a second thread to perform a second operation of the network test application, a second namespace, a second ANDR, and a second ANDR database, wherein the first ANDR of the first container and the second ANDR of the second container register the network test application, the first thread, and the second thread in each of the first ANDR database and the second ANDR database, and wherein the first ANDR of the first container sends a command and control message the second ANDR of the second container to utilize the second thread of the network test application running in a second domain of the second ANDR instead of launching the second thread in a first domain for the first ANDR.
- 10.** The network test instrument of claim 9, wherein the first thread of the first container comprises a user interface thread running in the first container, and the user interface thread collects user input for executing the network test application, and wherein the second thread of the second container comprises an input validation thread running in the second container, and the first ANDR of the first container determines that the input validation thread is running in the second domain based on an entry in the first ANDR database, and wherein the first ANDR transmits the command and control message to the second ANDR of the second container to run the input validation thread on the user input in the second domain.
- 11.** The network test instrument of claim 9, wherein the first ANDR determines that a hardware gating thread for the network test application is running in a different domain other than the first domain based on the first ANDR database, and transmits another command and control message to an ANDR of the different domain in a different container to cause the hardware gating thread to gate inputs based on an interrupt from a hardware abstraction layer thread.
- 12.** The network test instrument of claim 9, wherein the first ANDR of the first container determines that a network analysis thread and a system download thread for the network test application are running in a different domain other than the first domain, and transmits at least one other command and control message to an ANDR of the different domain in a different container to cause the network analysis thread and the system download thread to analyze and display test results.
- 13.** The network test instrument of claim 9, wherein the first ANDR of the first container searches the first ANDR database to determine whether the second thread is running in the second domain of the second ANDR of the second container.
- 14.** The network test instrument of claim 9, wherein the first and second ANDRs discover each other using an ANDR discovery protocol at container startup.
- 15.** The network test instrument of claim 9, wherein the command and control message comprises a destination address including a domain name of the second domain.
- 16.** The network test instrument of claim 9, wherein the first container is contained in a base module, and the second container is contained in a removable module attached to the base module.
- 17.** A method of executing a network test application in a test instrument to test a network, the network test application comprising threads running in containers in the test instrument, the method comprising: collecting user input for executing the network test application according to a user interface thread running in a first container of the containers; determining whether an input validation thread of the network test application is running in a second container of the containers based on an entry in a first application name discovery and routing service (ANDR) database maintained by a first ANDR running in the first container, wherein the first ANDR database includes entries that identify the threads of the network test application running in the containers; and in response to determining that the input validation thread is running in the second container, transmitting, by the first ANDR of the first container, a message to a second ANDR of the second container to run the input validation thread in the second container.

- 18.** The method of claim 17, further comprising: transmitting, from the first ANDR of the first container, another message to a third ANDR of a third container of the containers, wherein the third ANDR of the third container runs a hardware gating thread to gate an input based on a detected event or an interrupt from a Hardware Abstraction Layer thread for the network test application, and wherein the third container is identified in one of the entries in the first ANDR database.
- 19.** The method of claim 17, further comprising: transmitting, from the first ANDR of the first container, other messages to other ANDRs running in other containers of the containers to utilize a network analysis thread and a system download thread running in the other containers to analyze and display test results of the network test application on the test instrument, wherein the other containers are identified in the entries in the first ANDR database.
- 20.** The method of claim 19, wherein the system download thread downloads a template to display the test results of the network test application on the test instrument.
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