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(54) **SYNCHRONIZATION OF PHYSICAL FUNCTIONS AND VIRTUAL FUNCTIONS WITHIN A FABRIC**

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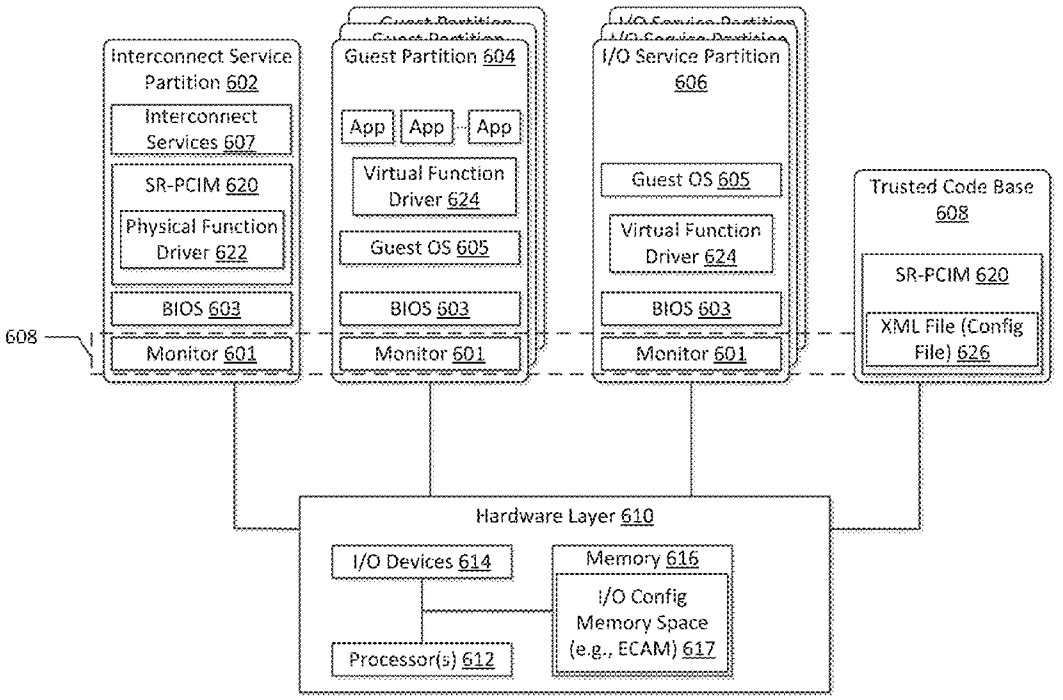
(57) **ABSTRACT**

Methods and systems for instantiating a virtual function in a partition of a multi-partition virtualization system implemented at least in part on a computing device are disclosed. One method includes initializing a partition on the computing device, including determining a virtual function to be associated with the partition, the virtual function associated with a physical function of an I/O device, and, prior to attaching a processor to the partition, determining if the physical function is in a ready state and capable of being associated with the virtual function. The method further includes, upon determining that the physical function is in the ready state and capable of being associated with the virtual function, attaching the processor to the partition, thereby allowing the partition to begin execution.



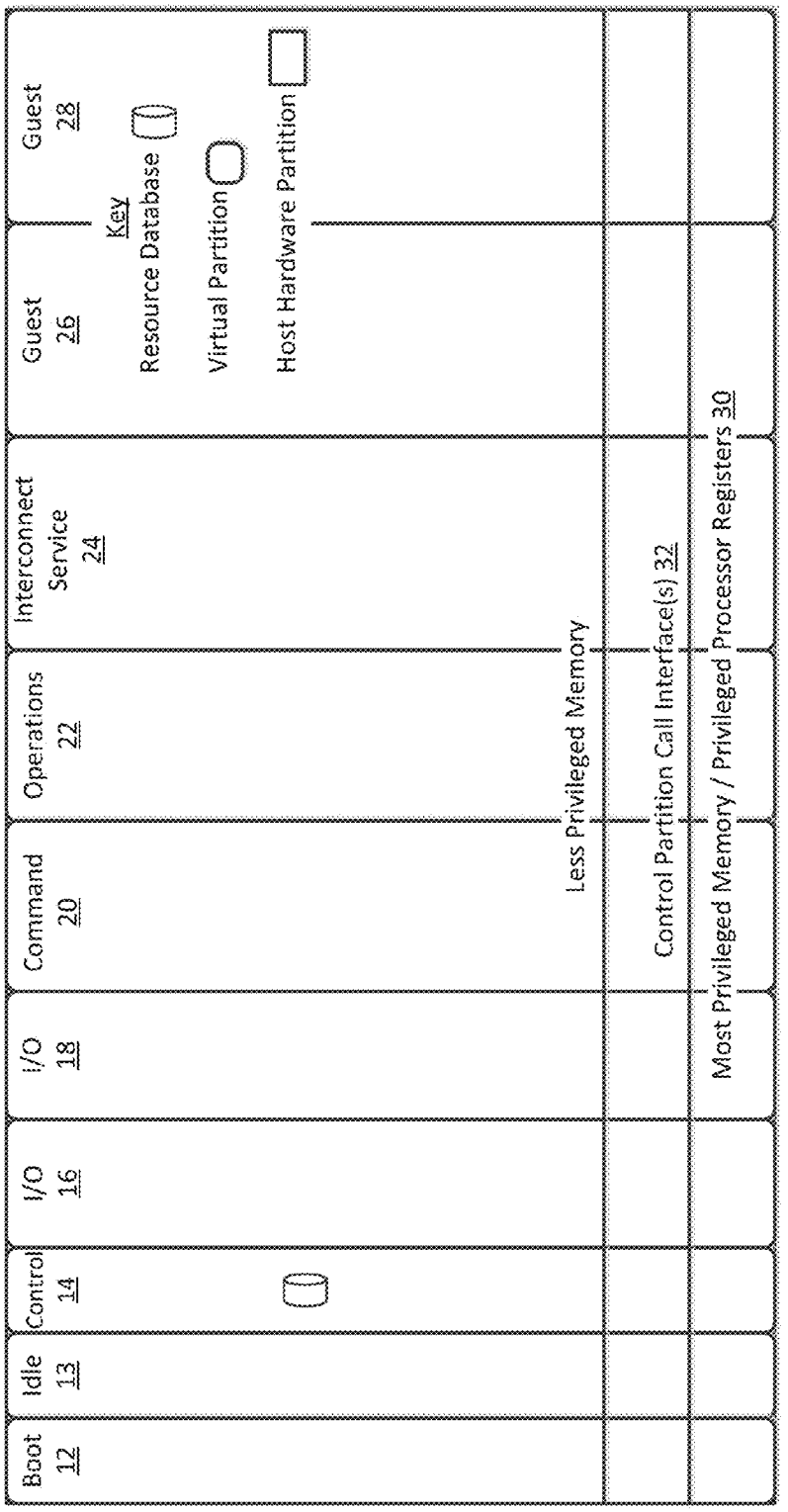

Boot 12
Idle 13
Control 14
I/O 16
I/O 18
Command 20
Operations 22
Interconnect Service 24
Guest 26
Guest 28
Key
Resource Database
Virtual Partition
Host Hardware Partition
Less Privileged Memory
Control Partition Call Interface(s) 32
Most Privileged Memory / Privileged Processor Registers 30
Partitioned Host System
10

FIG. 1

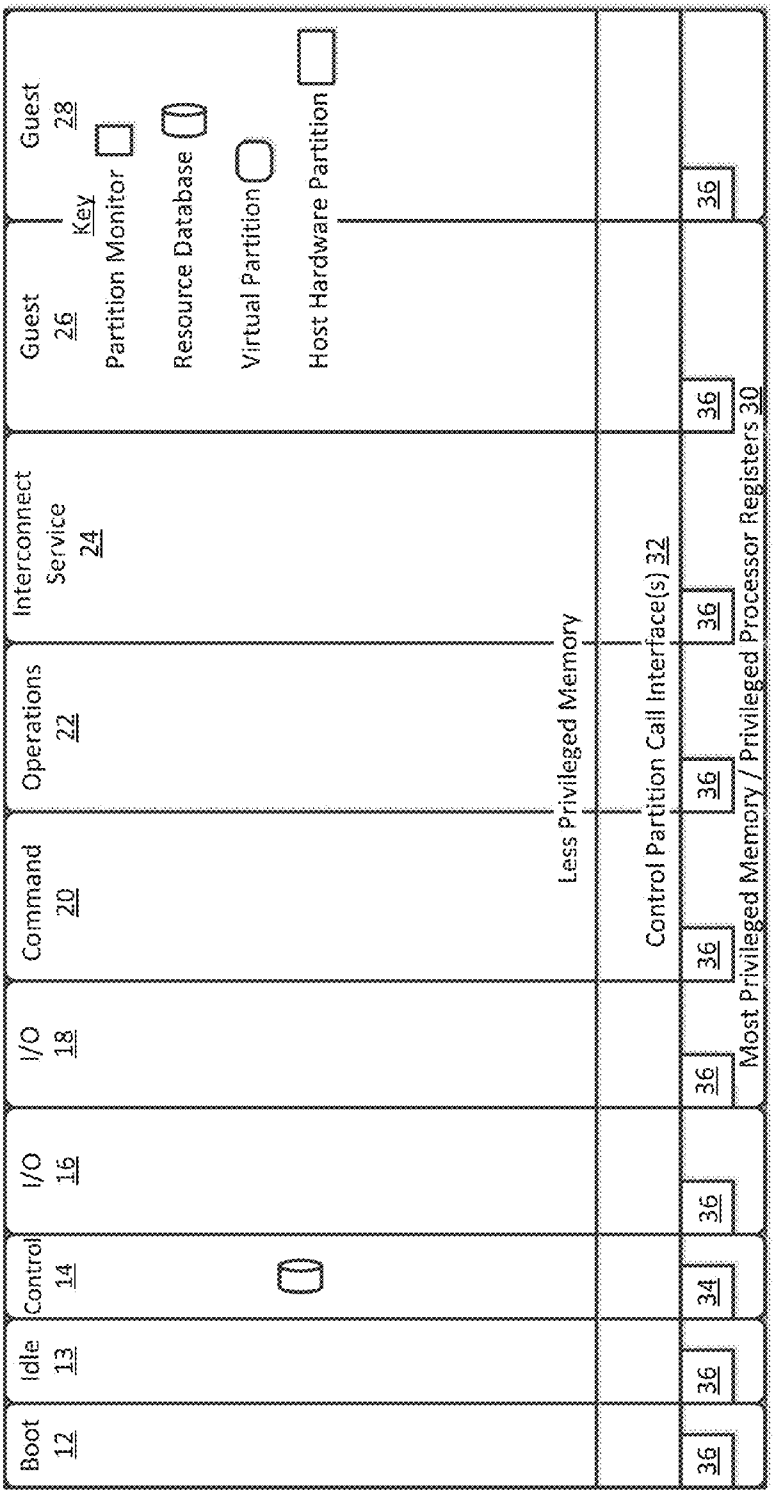

Boot 12
Idle 13
Control 14
I/O 16
I/O 18
Command 20
Operations 22
Interconnect Service 24
Guest 26
Key
Partition Monitor
Resource Database
Virtual Partition
Host Hardware Partition
Guest 28
Less Privileged Memory
Control Partition Call Interface(s) 32
Most Privileged Memory / Privileged Processor Registers 30
36
34
Partitioned Host System
10

FIG. 2

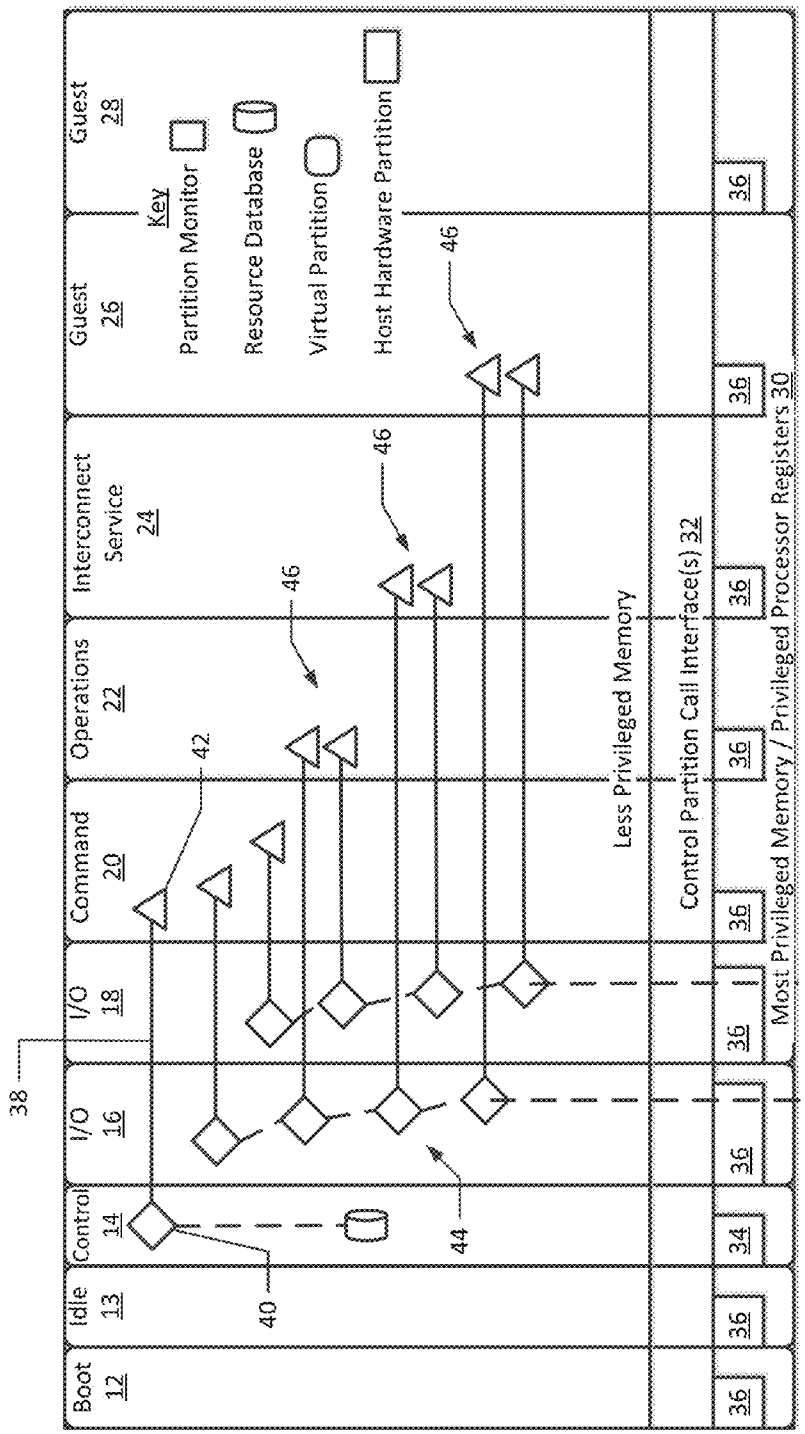

Boot 12
Idle 13
Control 14
I/O 16
I/O 18
Command 20
Operations 22
Interconnect Service 24
Guest 26
Guest 28
Key
Partition Monitor
Resource Database
Virtual Partition
Host Hardware Partition
Less Privileged Memory
Control Partition Call Interface(s) 32
Most Privileged Memory / Privileged Processor Registers 30
Partitioned Host System
36
34
38
40
42
44
46
10

FIG. 3

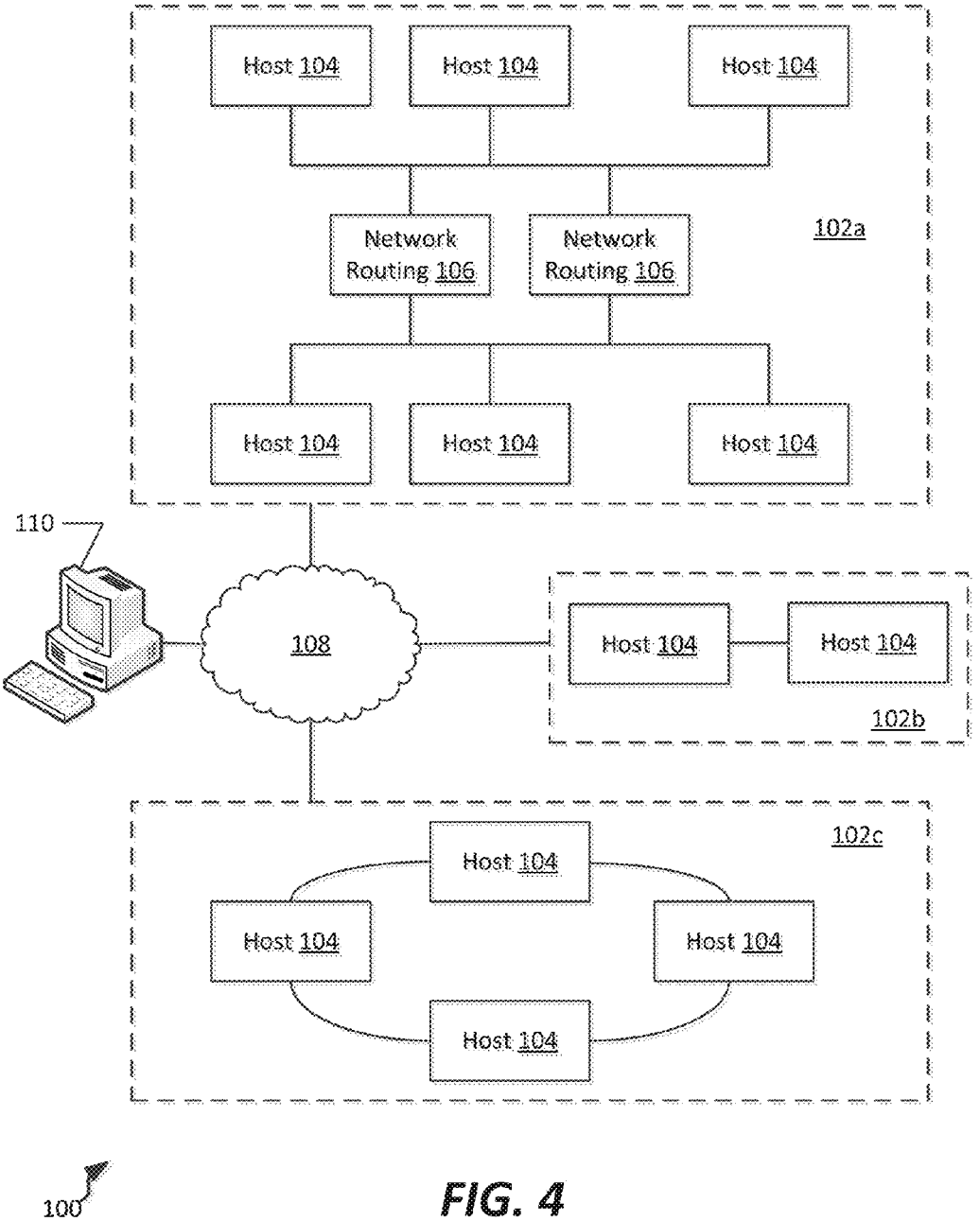

Host 104
Host 104
Host 104
Network Routing 106
Network Routing 106
102a
Host 104
Host 104
Host 104
110
108
Host 104
Host 104
102b
102c
Host 104
Host 104
Host 104
Host 104
100

FIG. 4

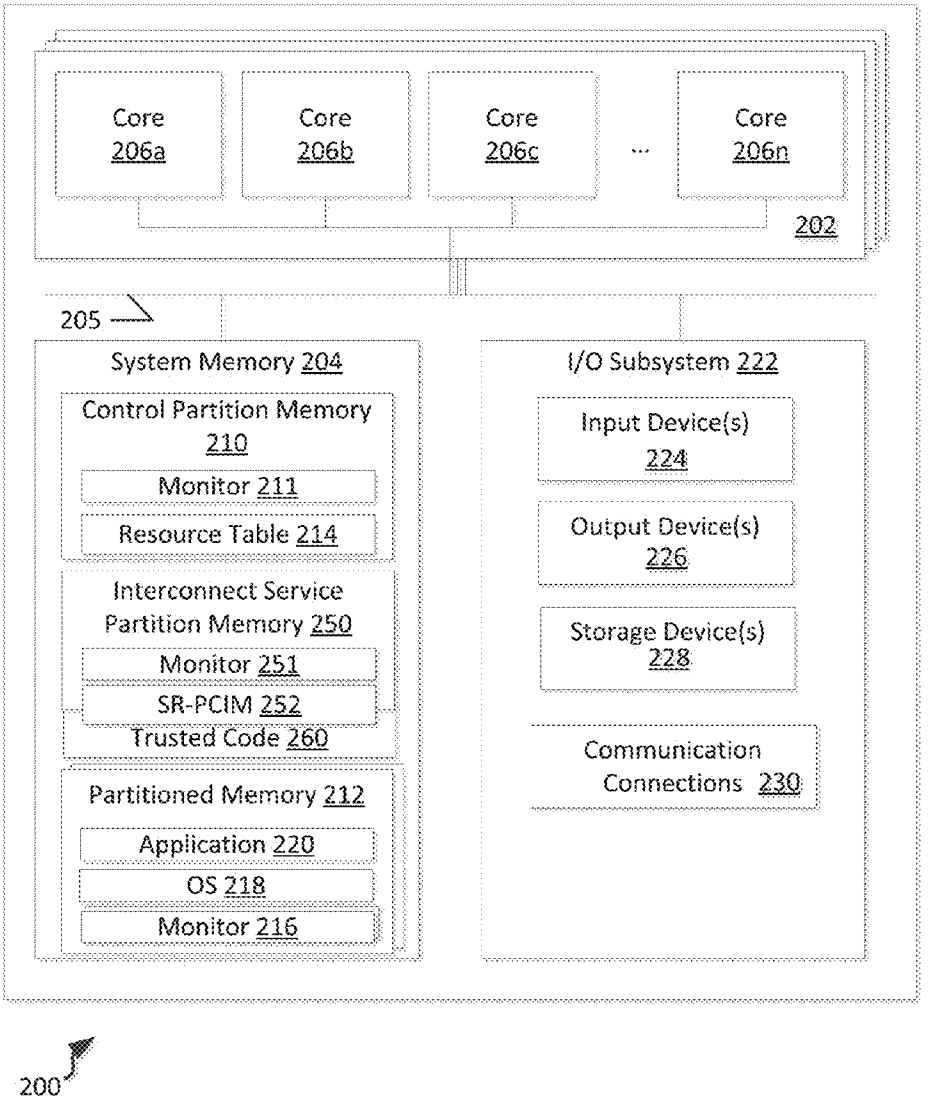

Core 206a
Core 206b
Core 206c
...
Core 206n
202
205
System Memory 204
Control Partition Memory 210
Monitor 211
Resource Table 214
Interconnect Service Partition Memory 250
Monitor 251
SR-PCIM 252
Trusted Code 260
Partitioned Memory 212
Application 220
OS 218
Monitor 216
I/O Subsystem 222
Input Device(s) 224
Output Device(s) 226
Storage Device(s) 228
Communication Connections 230
200

FIG. 5

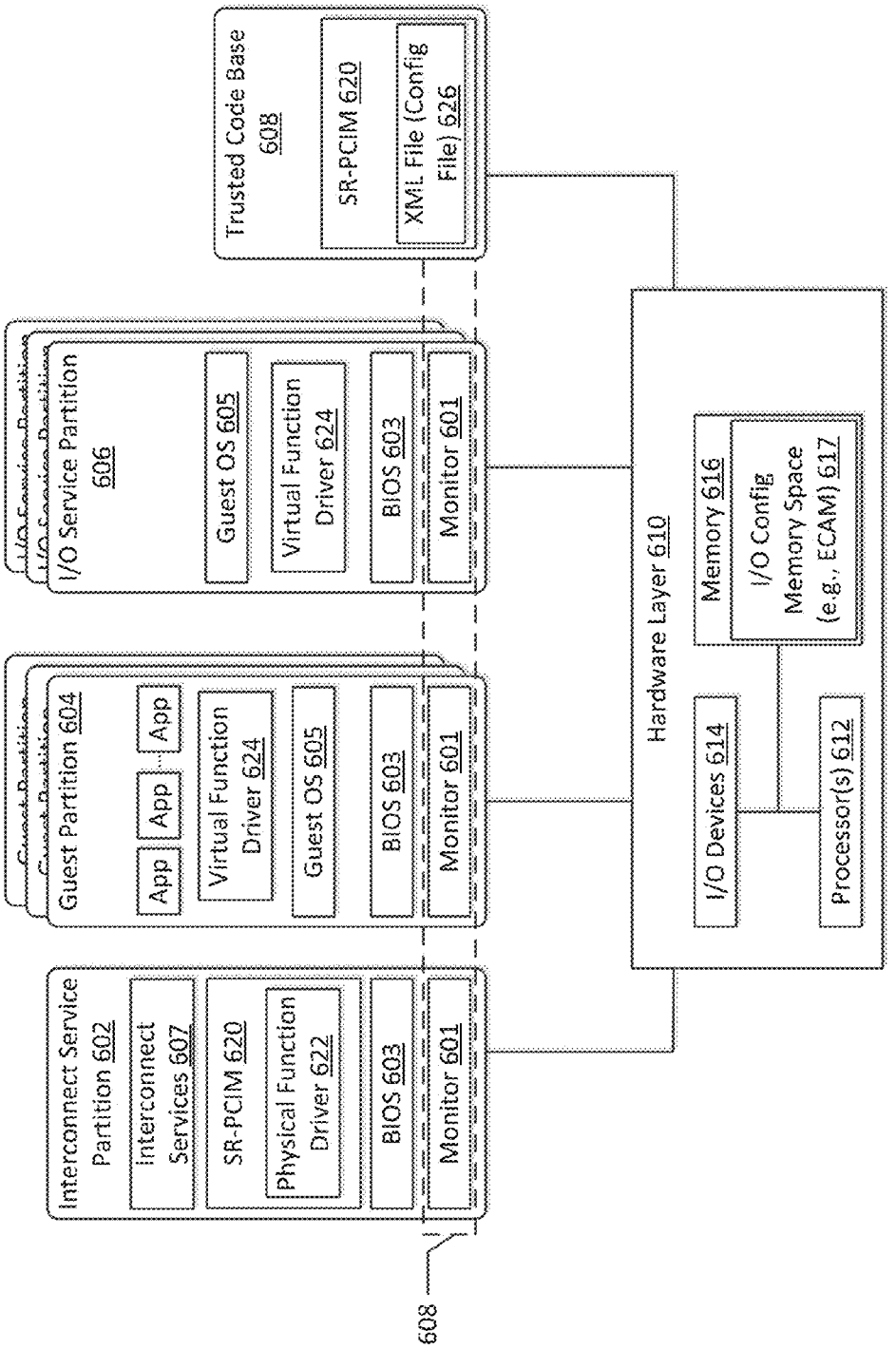

Trusted Code Base 608
SR-PCIM 620
XML File (Config File) 626
I/O Service Partition 606
Guest OS 605
Virtual Function Driver 624
BIOS 603
Monitor 601
Guest Partition 604
App
App
App
Virtual Function Driver 624
Guest OS 605
BIOS 603
Monitor 601
Interconnect Service Partition 602
Interconnect Services 607
SR-PCIM 620
Physical Function Driver 622
BIOS 603
Monitor 601
608
Hardware Layer 610
I/O Devices 614
Memory 616
I/O Config Memory Space (e.g., ECAM) 617
Processor(s) 612

FIG. 6

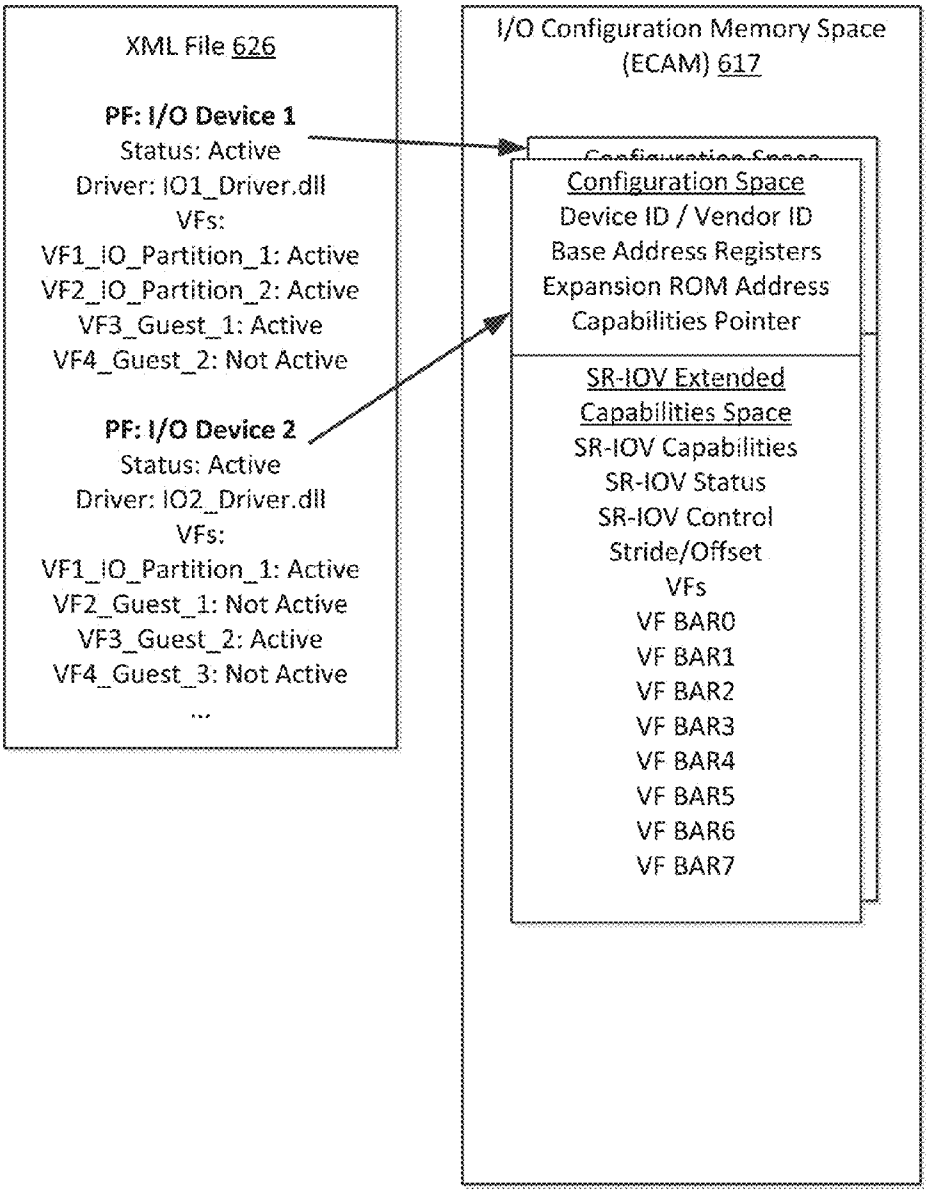

XML File 626
PF: I/O Device 1
Status: Active
Driver: IO1_Driver.dll
VFs:
VF1_IO_Partition_1: Active
VF2_IO_Partition_2: Active
VF3_Guest_1: Active
VF4_Guest_2: Not Active
PF: I/O Device 2
Status: Active
Driver: IO2_Driver.dll
VFs:
VF1_IO_Partition_1: Active
VF2_Guest_1: Not Active
VF3_Guest_2: Active
VF4_Guest_3: Not Active
...
I/O Configuration Memory Space (ECAM) 617
Configuration Space
Device ID / Vendor ID
Base Address Registers
Expansion ROM Address
Capabilities Pointer
SR-IOV Extended Capabilities Space
SR-IOV Capabilities
SR-IOV Status
SR-IOV Control
Stride/Offset
VFs
VF BAR0
VF BAR1
VF BAR2
VF BAR3
VF BAR4
VF BAR5
VF BAR6
VF BAR7

FIG. 7

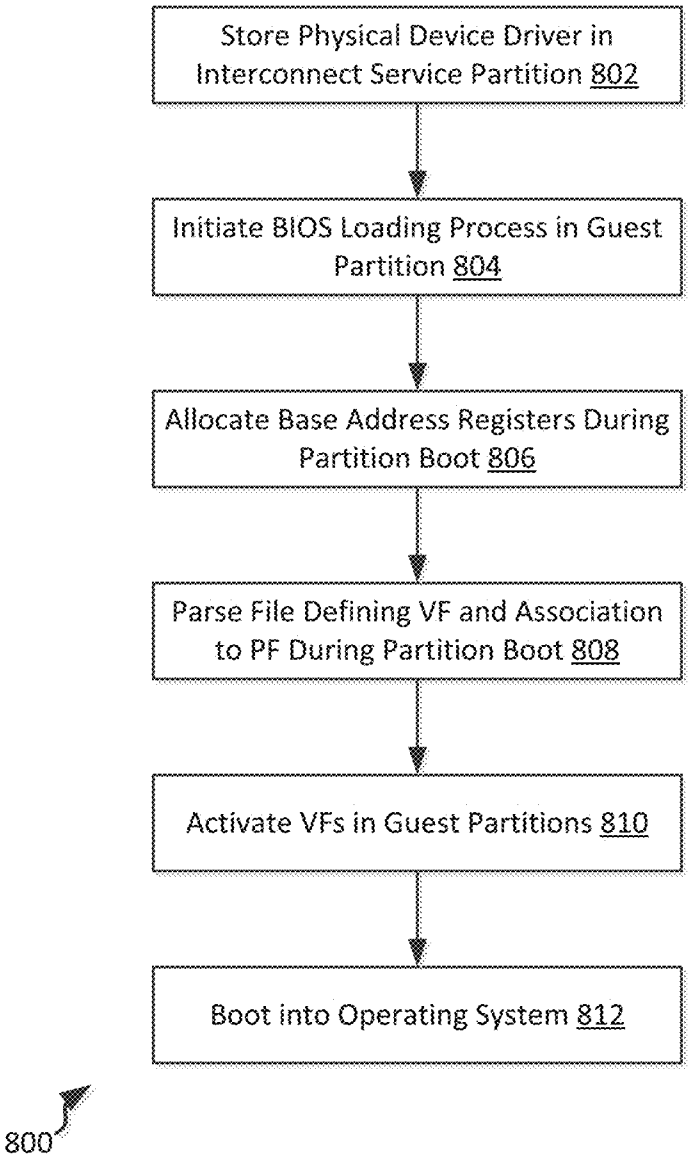

Store Physical Device Driver in Interconnect Service Partition 802
Initiate BIOS Loading Process in Guest Partition 804
Allocate Base Address Registers During Partition Boot 806
Parse File Defining VF and Association to PF During Partition Boot 808
Activate VFs in Guest Partitions 810
Boot into Operating System 812
800

FIG. 8

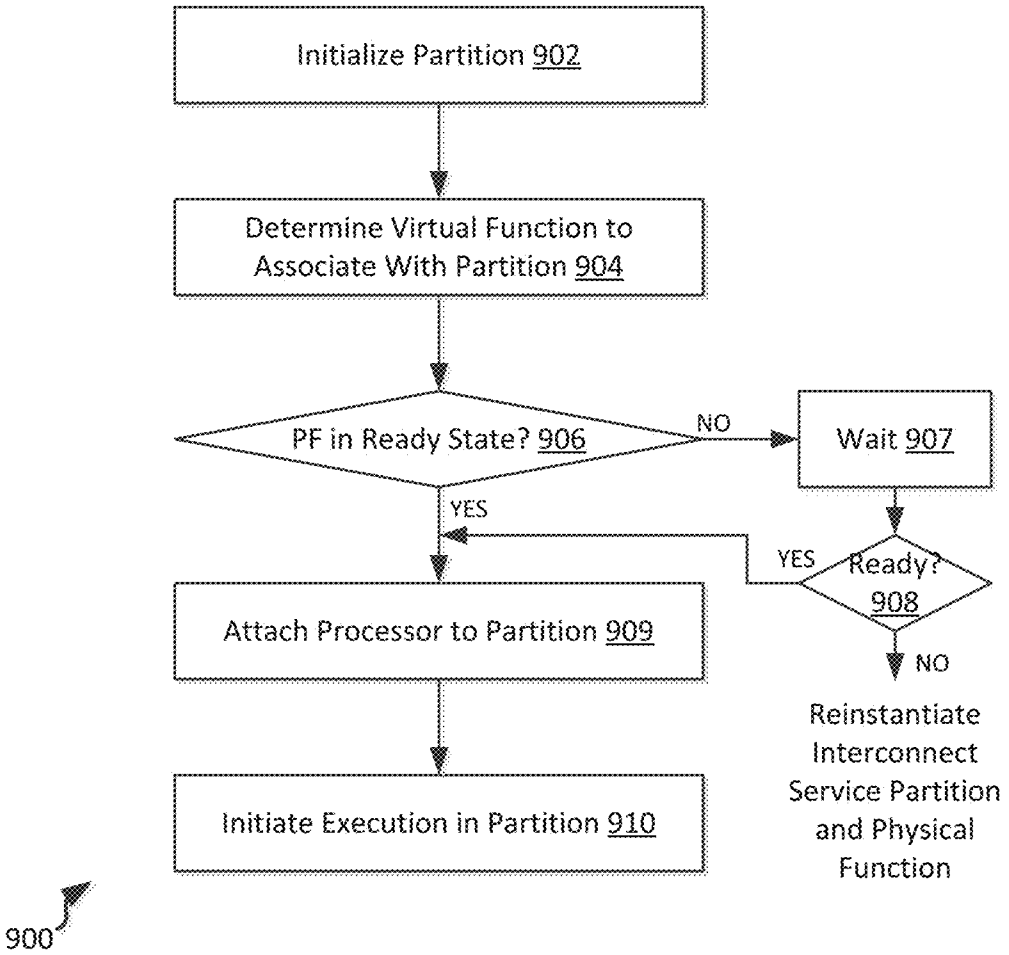

Initialize Partition 902
Determine Virtual Function to Associate With Partition 904
PF in Ready State? 906
NO
Wait 907
YES
YES
Ready? 908
NO
Attach Processor to Partition 909
Initiate Execution in Partition 910
Reinstantiate Interconnect Service Partition and Physical Function
900

FIG. 9

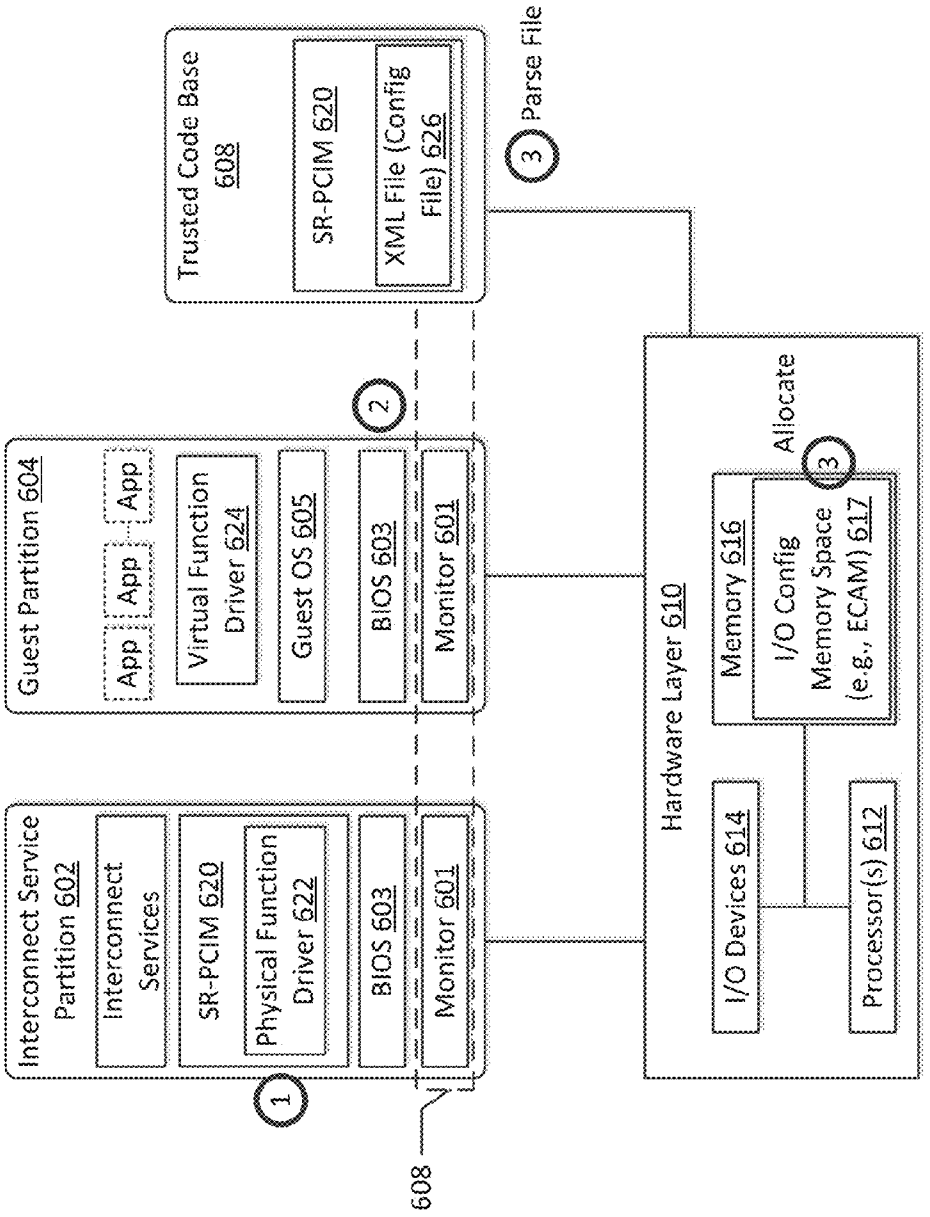

Interconnect Service Partition 602
Interconnect Services
SR-PCIM 620
Physical Function Driver 622
BIOS 603
Monitor 601
Guest Partition 604
App
App
App
Virtual Function Driver 624
Guest OS 605
BIOS 603
Monitor 601
Trusted Code Base 608
SR-PCIM 620
XML File (Config File) 626
Parse File
Hardware Layer 610
I/O Devices 614
Memory 616
I/O Config Memory Space (e.g., ECAM) 617
Allocate
Processor(s) 612
1
2
3
3
608

FIG. 10A

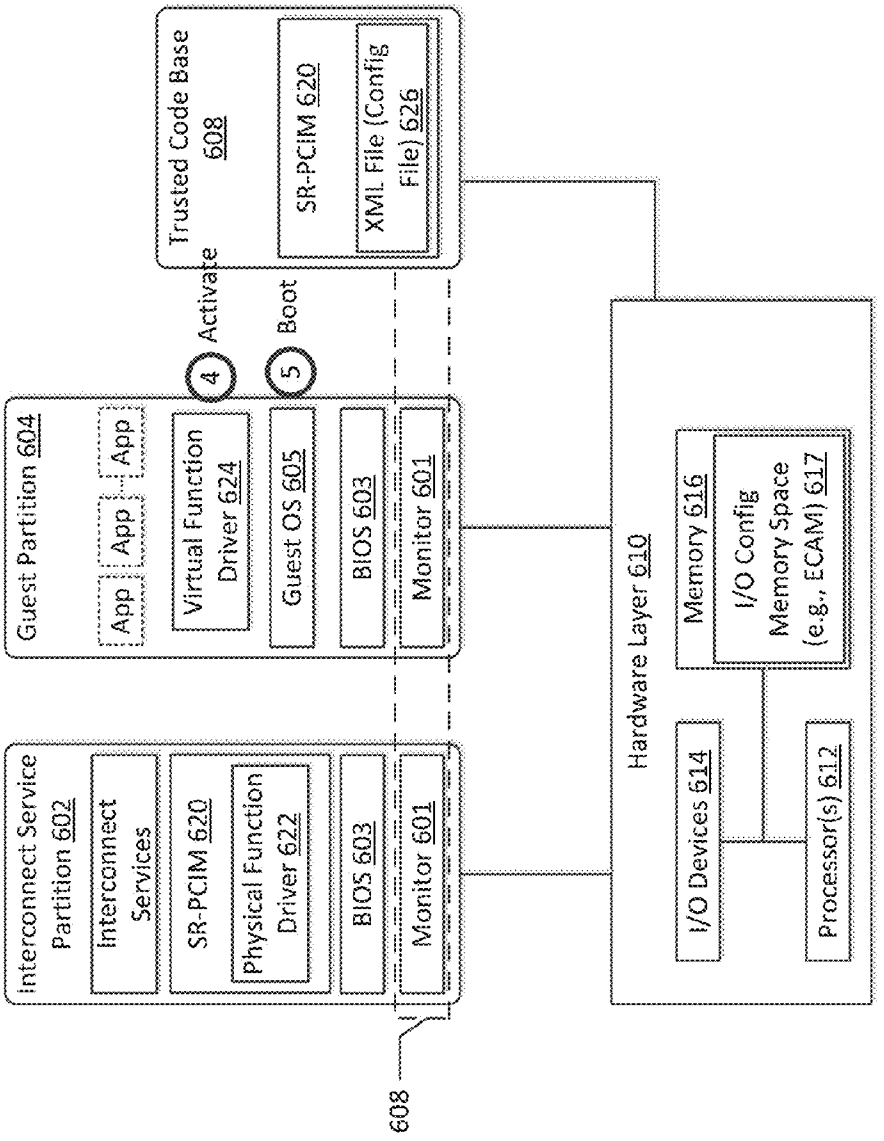

Trusted Code Base 608
SR-PCIM 620
XML File (Config File) 626
4 Activate
5 Boot
Guest Partition 604
App
App
App
Virtual Function Driver 624
Guest OS 605
BIOS 603
Monitor 601
Interconnect Service Partition 602
Interconnect Services
SR-PCIM 620
Physical Function Driver 622
BIOS 603
Monitor 601
608
Hardware Layer 610
Memory 616
I/O Config Memory Space (e.g., ECAM) 617
I/O Devices 614
Processor(s) 612

FIG. 10B

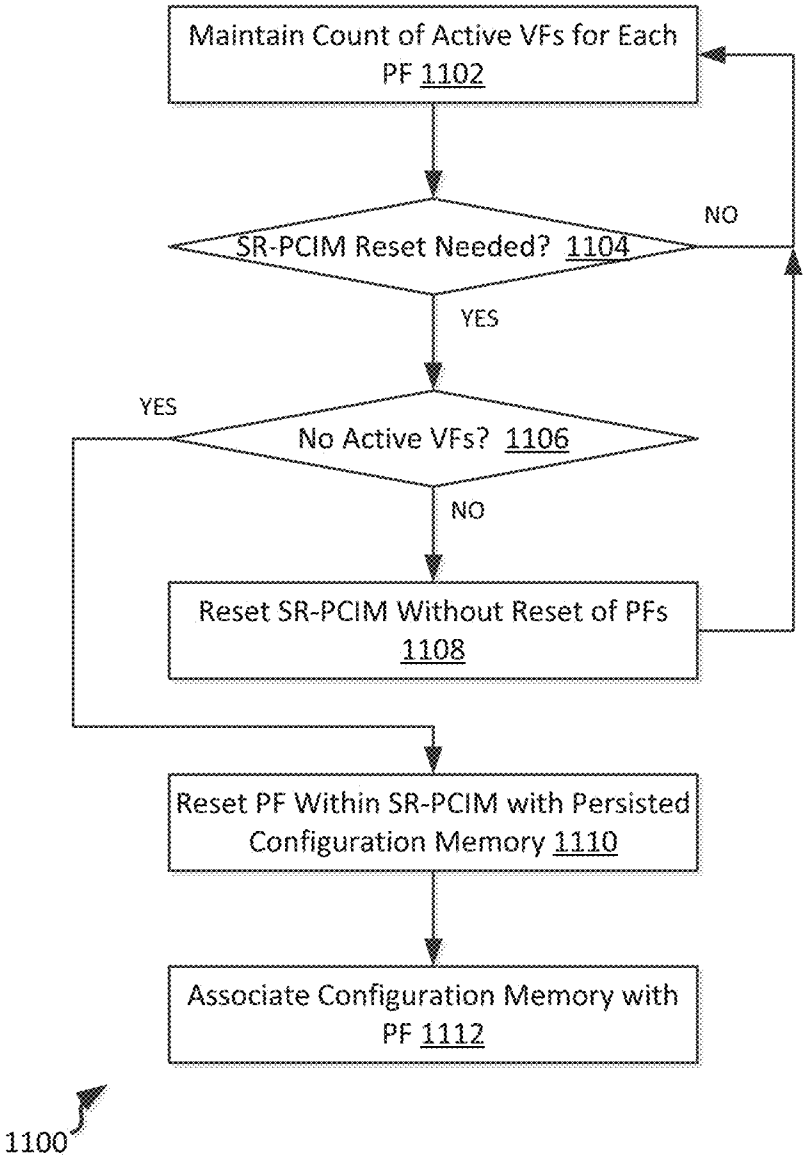

Maintain Count of Active VFs for Each PF 1102
SR-PCIM Reset Needed? 1104
NO
YES
YES
No Active VFs? 1106
NO
Reset SR-PCIM Without Reset of PFs 1108
Reset PF Within SR-PCIM with Persisted Configuration Memory 1110
Associate Configuration Memory with PF 1112
1100

FIG. 11

SYNCHRONIZATION OF PHYSICAL FUNCTIONS AND VIRTUAL FUNCTIONS WITHIN A FABRIC

TECHNICAL FIELD

[0001] The present application relates generally to virtualization systems, and in particular to single-root input/output virtualization in a distributed multi-partition virtualization system.

BACKGROUND

[0002] Computer system virtualization allows multiple operating systems and processes to share the hardware resources of a host computer. Ideally, the system virtualization provides resource isolation so that each operating system does not realize that it is sharing resources with another operating system and does not adversely affect the execution of the other operating system. Such system virtualization enables applications including server consolidation, co-located hosting facilities, distributed web services, applications mobility, secure computing platforms, and other applications that provide for efficient use of underlying hardware resources.

[0003] Existing virtualization systems, such as those provided by VMWare and Microsoft, have developed relatively sophisticated virtualization systems that are architected as a monolithic virtualization software system that hosts each virtualized system. In other words, these virtualization systems are constructed to host each of the virtualized systems on a particular computing platform. As such, the virtualization systems or virtual machine monitors (VMMs) associate hardware resources of a particular platform with each partition. Typically, this involves sharing of resources across multiple partitions. For example, two partitions may share a same processor and memory resource (although may be separated by address ranges or otherwise maintained to ensure isolated memory management). Furthermore, two such partitions may also share input/output devices, such as keyboards, mice, printing ports, Ethernet ports, or other communications interfaces,

[0004] Recently, technologies have been introduced that simplify sharing of I/O devices in a computing system across a plurality of virtual machines. Such technologies include Single-Root Input/Output Virtualization (SR-IOV), which allows a single physical device to be made available to multiple separate virtual devices without requiring the virtualization system to manage time-sharing of the device across such virtual machines that wish to share the I/O device. In particular, SR-IOV is intended to standardize a way of bypassing a VMM's involvement in data movement by providing independent memory space, interrupts, and DMA streams for each virtual machine. SR-IOV architecture is designed to allow a device to support multiple Virtual Functions (VFs) while minimizing the hardware cost of each additional function.

[0005] SR-IOV-compatible I/O devices are defined by two primary function types—physical functions (PFs) and virtual functions (VFs). Physical functions are full PCIe functions that include the SR-IOV Extended Capability, which is used to configure and manage the SR-IOV functionality. Virtual functions are 'lightweight' PCIe functions that contain the resources necessary for data movement but have a carefully minimized set of configuration resources. Each virtual function is associated with a physical function, and relies on the physical function for execution.

[0006] Because existing SR-IOV technologies are managed entirely by the VMM associated with a particular virtualization architecture, such I/O devices are dependent upon continued operation of the VMM for continued proper operation of the I/O device. Additionally, by managing the SR-IOV instance, and in particular the physical function, the VMM is required to directly manage I/O functionality, rather than allowing an operating system or some other system specialized to that task. Additionally, because such VMMs are typically a monolithic software system, in case of failure of such a VMM, the entire I/O device will become unusable.

[0007] For these and other reasons, improvements are desirable.

SUMMARY

[0008] In summary, the present disclosure relates to virtualization systems, and in particular to methods and systems for managing I/O devices in such virtualization systems. In example aspects of the present disclosure, management of single-root I/O virtualization systems is provided in a distributed multi-partition virtualization system

[0009] In a first aspect, a method for instantiating a virtual function in a partition of a multi-partition virtualization system implemented at least in part on a computing device are disclosed. The method includes initializing a partition on the computing device, including determining a virtual function to be associated with the partition, the virtual function associated with a physical function of an I/O device, and, prior to attaching a processor to the partition, determining if the physical function is in a ready state and capable of being associated with the virtual function. The method further includes, upon determining that the physical function is in the ready state and capable of being associated with the virtual function, attaching the processor to the partition, thereby allowing the partition to begin execution.

[0010] In a second aspect, a system includes a first partition implemented on a computing system including a plurality of processors, memory, and at least one I/O device having an associated physical function, the physical function having a plurality of operational states including a ready state, and a second partition implemented on the computing system, the second partition capable of having at least one of the plurality of processors associated therewith to initiate execution of the second partition and having a virtual function associated with the physical function. The system is configured to determine, or to associating the at least one of the plurality of processors therewith, whether the physical function is in at least the ready state. If the physical function is not in at least the ready state, the system prevents association of any of the plurality of processors with the second partition.

[0011] In a third aspect, a computer readable storage medium having computer-executable instructions stored thereon, which, when executed by a computing system, cause the computing system to perform a method of instantiating a virtual function in a partition of a multi-partition virtualization system implemented at least in part on a computing device. The method includes initializing a partition on the computing device, including determining a virtual function to be associated with the partition, the virtual function associated with a physical function of an I/O device of the computing system, and, prior to attaching a processor to the partition, determining if the physical function is in at least a ready state.

The method further includes, while the physical function is not in at least the ready state, maintaining the partition in a processors attached state, thereby preventing instantiation of an operating system within the partition. The method also includes, upon determining that the physical function is in at least the ready state, attaching the processor to the partition, thereby allowing the partition to begin execution.

[0012] This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This summary is not intended to identify key features or, essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] FIG. **1** illustrates system infrastructure partitions in an exemplary embodiment of a host system partitioned using the para-virtualization system of the present disclosure;

[0014] FIG. **2** illustrates the partitioned host of FIG. **1** and the associated partition monitors of each partition;

[0015] FIG. **3** illustrates memory mapped communication channels amongst various partitions of the para-virtualization system of FIG. **1**;

[0016] FIG. **4** illustrates a distributed multi-host system in which aspects of the present disclosure can be implemented;

[0017] FIG. **5** illustrates an example block diagram of a host computing system useable to implement the para-virtualization systems of FIGS. **1-3**, above;

[0018] FIG. **6** illustrates a general block diagram of a multi-partition system managing SR-IOV device operations in a para-virtualization system of the present disclosure, according to an example embodiment;

[0019] FIG. **7** illustrates an example markup language file useable to track SR-IOV device mappings and status within a partition lacking access to privileged memory, according to an example embodiment;

[0020] FIG. **8** illustrates a flowchart of a method of managing physical and virtual functions of an I/O device according to an example embodiment;

[0021] FIG. **9** illustrates a flowchart of a method of associating a virtual function of an I/O device to a partition, according to an example embodiment;

[0022] FIGS. **10A-10B** illustrate processes by which physical and virtual functions can be managed in the example multi-partition system of FIG. **6**; and

[0023] FIG. **11** illustrates an example method of managing a physical function and single root I/O manager in a partition of a multi-partition system, according to an example embodiment.

DETAILED DESCRIPTION

[0024] Various embodiments of the present invention will be described in detail with reference to the drawings, wherein like reference numerals represent like parts and assemblies throughout the several views. Reference to various embodiments does not limit the scope of the invention, which is limited only by the scope of the claims attached hereto. Additionally, any examples set forth in this specification are not intended to be limiting and merely set forth some of the many possible embodiments for the claimed invention.

[0025] The logical operations of the various embodiments of the disclosure described herein are implemented as: (1) a sequence of computer implemented steps, operations, or procedures running on a programmable circuit within a computer, and/or (2) a sequence of computer implemented steps, operations, or procedures running on a programmable circuit within a directory system, database, or compiler.

[0026] As briefly described above, embodiments of the present disclosure are directed to methods and systems for managing input/output (I/O) devices in a multi-partition virtualized system, and in particular managing such devices using systems provided within the partitions themselves, thereby accounting for failures of either the I/O devices themselves or the partitions in which they reside.

[0027] According to example embodiments discussed herein, a single root I/O manager (SR-IOM) can be managed within a partition itself, rather than within a virtual machine monitor (VMM), thereby allowing the SR-IOM to be reset as needed, and to preserve the physical function and instance of the SR-IOM through failures of a particular VMM. The methods and systems discussed herein provide for management of physical functions and virtual functions, while providing a mechanism allowing the virtual machine (rather than the virtualization software itself, or VMM) to have access to privileged memory at the hardware level that is used for SR-IOV mappings.

[0028] In the context of the present disclosure, virtualization software generally corresponds to software that executes natively on a computing system, through which non-native software can be executed by hosting that software. In such cases, the virtualization software exposes those native resources in a way that is recognizable to the non-native software. By way of reference, non-native software, otherwise referred to herein as "virtualized software" or a "virtualized system", refers to software not natively executed on a particular hardware system, for example due to it being written for execution by a different type of microprocessor configured to execute a different native instruction set. In some of the examples discussed herein, the native software set can be the x86-32, x86-64, or IA64 instruction set from Intel Corporation of Sunnyvale, Calif., while the non-native or virtualized system might be compiled for execution on an OS2200 system from Unisys Corporation of Blue Bell, Pa. However, it is understood that the principles of the present disclosure are not thereby limited; rather, non-native software simply can correspond to software not hosted or executed directly on hardware resources in the absence of a monitor system used to manage such execution, and to provide an abstraction layer between the application or workload to be executed and the underlying hardware resources,

I. Para-Virtualizaton System Architecture

[0029] Referring to FIG. **1**, an example arrangement of a para-virtualization system is shown that can be used in implementing the SR-IOV-based the features mentioned above. In some embodiments, the architecture discussed herein uses the principle of least privilege to run code at the lowest practical privilege. To do this, special infrastructure partitions run resource management and physical I/O device drivers, FIG. **1** illustrates system infrastructure partitions on the left and user guest partitions on the right. Host hardware resource management runs as a control application in a special control partition. This control application implements a server for a command channel to accept transactional requests for assignment of resources to partitions. The control application maintains the master in-memory database of the hardware resource

allocations. The control application also provides a read only view of individual partitions to the associated partition monitors,

[0030] In FIG. **1**, partitioned host (hardware) system (or node), shown as host computing system **10**, has lesser privileged memory that is divided into distinct partitions including special infrastructure partitions such as boot partition **12**, idle partition **13**, control partition **14**, first and second I/O partitions **16** and **18**, command partition **20**, operations partition **22**, and interconnect service partition **24**, as well as virtual guest partitions **26** and **28**. As illustrated, the partitions **12-28** do not directly access the underlying privileged memory and processor registers **30** but instead accesses the privileged memory and processor registers **30** via a hypervisor system call interface **32** that provides context switches amongst the partitions **12-28** in a conventional fashion. Unlike conventional VMMs and hypervisors, however, the resource management functions of the partitioned host computing system **10** of FIG. **1** are implemented in the special infrastructure partitions **12-22**. Furthermore, rather than requiring re-write of portions of the guest operating system, drivers can be provided in the guest operating system environments that can execute system calls. As explained in further detail in U.S. Pat. No. 7,984,104, assigned to Unisys Corporation of Blue Bell, Pa., these special infrastructure partitions **12-24** control resource management and physical I/O device drivers that are, in turn, used by operating systems operating as guests in the guest partitions **26-28**. Of course, many other guest partitions may be implemented in a particular host computing system **10** partitioned in accordance with the techniques of the present disclosure.

[0031] A boot partition **12** contains the host hoot firmware and functions to initially load the control, I/O and command partitions (elements **14-20**). Once launched, the resource management "control" partition **14** includes minimal firmware that tracks resource usage using a tracking application referred to herein as a control or resource management application. Host resource management decisions are performed in command partition **20** and distributed decisions amongst partitions in one or more host computing systems **10** are managed by operations partition **22**. I/O to disk drives and the like is controlled by one or both of I/O partitions **16** and **18** so as to provide both failover and load balancing capabilities. Operating systems in the guest partitions **24**, **26**, and **28** communicate with the I/O partitions **16** and **18** via memory channels (FIG. **3**) established by the control partition **14**. The partitions communicate only via the memory channels. Hardware I/O resources are allocated only to the I/O partitions **16**, **18**. In the configuration of FIG. **1**, the hypervisor system call interface **32** is essentially reduced to context switching and containment elements (monitors) for the respective partitions.

[0032] The resource manager application of the control partition **14**, shown as application **40** in FIG. **3**, manages a resource database **33** that keeps track of assignment of resources to partitions and further serves a command channel **38** to accept transactional requests for assignment of the resources to respective partitions. As illustrated in FIG. **2**, control partition **14** also includes a partition (lead) monitor **34** that is similar to a virtual machine monitor (VMM) except that it provides individual read-only views of the resource database in the control partition **14** to associated partition monitors **36** of each partition. Thus, unlike conventional VMMs, each partition has its own monitor **36** per vCPU of the partition such that failure of the monitor **36** does not bring down the entire host computing system **10**. As will be explained below, the guest operating systems in the respective partitions **26**, **28** (referred to herein as "guest partitions") are modified to access the associated partition monitors **36** that implement together with hypervisor system call interface **32** a communications mechanism through which the control, I/O, and any other special infrastructure partitions **14-24** may initiate communications with each other and with the respective guest partitions.

[0033] The partition monitors **36** in each partition constrain the guest OS and its applications to the assigned resources. Each monitor **36** implements a system call interface **32** that is used by the guest OS of its partition to request usage of allocated resources. The system call interface **32** includes protection exceptions that occur when the guest OS attempts to use privileged processor op-codes. Different partitions can use different monitors **36**. This allows support of multiple system call interfaces **32** and for these standards to evolve over time. It also allows independent upgrade of monitor components in different partitions.

[0034] The monitor **36** is preferably aware of processor capabilities so that it may he optimized to utilize any available processor virtualization support. With appropriate monitor **36** and processor support, a guest OS in a guest partition (e.g., **26**, **28**) need not be aware of the control system of the invention and need not make any explicit 'system' calls to the monitor **36**. In this case, processor virtualization interrupts provide the necessary and sufficient system call interface **32**. However, to optimize performance, explicit calls from a guest OS to a monitor system call interface **32** are still desirable.

[0035] The monitor **36** also maintains a map of resources allocated to the partition it monitors and ensures that the guest OS (and applications) in its partition use only the allocated hardware resources. The monitor **36** can do this since it is the first code running in the partition at the processor's most privileged level. The monitor **36** boots the partition firmware at a decreased privilege. The firmware subsequently boots the OS and applications. Normal processor protection mechanisms prevent the firmware, OS, and applications from ever obtaining the processor's most privileged protection level.

[0036] Unlike a conventional VMM, a monitor **36** has no I/O interfaces. All I/O is performed by I/O hardware mapped to I/O partitions **16**, **18** that use memory channels to communicate with their client partitions. A responsibility of a monitor **36** is instead to protect processor provided resources (e,g., processor privileged functions and memory management units). The monitor **36** also protects access to I/O hardware primarily through protection of memory mapped I/O. The monitor **36** further provides channel endpoint capabilities which are the basis for I/O capabilities between guest partitions.

[0037] The monitor **34** for the control partition **14** is a "lead" monitor with two special roles. It creates and destroys monitors **36**, and also provides services to the created monitors **36** to aid processor context switches. During a processor context switch, monitors **34**, **36** save the guest partition state in the virtual processor structure, save the privileged state in virtual processor structure and then invoke the control monitor switch service. This service loads the privileged, state of the target partition monitor and switches to the target partition monitor which then restores the remainder of the guest partition state.

[0038] The most privileged processor level (e.g., x86 ring 0) is retained by having the monitors **34**, **36** running below the system call interface **32**. This is most effective if the processor implements at least three distinct protection levels: e.g., x86 ring 1, 2, and 3 available to the guest OS and applications. The control partition **14** connects to the monitors **34**, **36** at the base (most privileged level) of each partition. The monitor **34** grants itself read only access to the partition descriptor in the control partition **14**, and the control partition **14** has read only access to one page of monitor state stored in the resource database **33**.

[0039] Those skilled in the art will appreciate that the monitors **34**, **36** of the invention are similar to a classic VMM in that they constrain the partition to its assigned resources, interrupt handlers provide protection exceptions that emulate privileged behaviors as necessary, and system call interfaces are implemented for "aware" contained, system code. However, as explained in further detail below, the monitors **34**, **36** of the invention are unlike a classic in that the master resource database **33** is contained in a virtual (control) partition for recoverability, the resource database **33** implements a simple transaction mechanism, and the virtualized system is constructed from a collection of cooperating monitors **34**, **36** whereby a failure in one monitor **34**, **36** need not result in failure of all partitions and need not result in the failure of a multiprocessor/multi-core partition; in particular, any symmetric multiprocessing system can, due to use of a monitor per execution core, preserve operation of the partition using remaining execution cores. Furthermore, failure of a single physical processing unit need not result in failure of all partitions of a system, since partitions are affiliated with different processing units.

[0040] The monitors **34**, **36** of the invention are also different from classic VMMs in that each partition is contained by its assigned monitor(s), partitions with simpler containment requirements can use simpler and thus more reliable (and higher security) monitor implementations, and the monitor implementations for different partitions may, but need not be, shared. Also, unlike conventional VMMs, a lead monitor **34** provides access by other monitors **36** to the control partition resource database **33**.

[0041] Partitions in the control environment include the available resources organized by host computing system **10**. Available computing resources in a host node, also referred to herein as a host computing system are described by way of example in FIGS. **4-5**. Generally, a partition is a software construct (that may be partially hardware assisted) that allows a hardware system platform (or hardware partition) to be "partitioned," or separated., into independent operating environments. The degree of hardware assist (e.g., physical hardware separation) is platform dependent but by definition is less than 100% (since by definition a 100% hardware assist provides hardware partitions). The hardware assist may be provided by the processor or other platform hardware features. For example, each partition may be associated with a separate processing core or cores, but may each be associated with a separate portion of the same system memory, networking resources, or other features. Or, partitions may time-share processing resources, but be associated with separate memory, networking, and/or peripheral devices. In general from the perspective of the control partition **14**, a hardware partition is generally indistinguishable from a commodity hardware platform without partitioning hardware.

[0042] Unused physical processors are assigned to an 'Idle' partition **13**. The idle partition **13** is the simplest partition that is assigned processor resources. It contains a virtual processor for each available physical processor, and each virtual processor executes an idle loop that contains appropriate processor instructions to minimize processor power usage. The idle virtual processors may cede time at the next control time quantum interrupt and the monitor **36** of the idle partition **13** may switch processor context to a virtual processor in a different partition. During host bootstrap, the boot processor of the boot partition **12** boots all of the other processors into the idle partition **13**.

[0043] In some embodiments, multiple control partitions **14** are also possible for large host partitions to avoid a single point of failure. Each would be responsible for resources of the appropriate portion of the host computing system **10**. Resource service allocations would be partitioned in each portion of the host system **10**. This allows clusters to run within a host computing system **10** (one cluster node in each zone) and still survive failure of a control partition **14**.

[0044] As illustrated in FIGS. **1-3**, each page of memory in a control partition-enabled host computing system **10** is owned by one of its partitions. Additionally, each hardware I/O device is mapped to one of the designated I/O partitions **16**, **18**. These I/O partitions **16**, **18** (typically two for redundancy) run special software that allows the I/O partitions **16**, **18** to run the I/O channel server applications for sharing the I/O hardware. Alternatively, for I/O partitions executing using a processor implementing Intel's VT-d technology, devices can be assigned directly to non-I/O partitions. Irrespective of the manner of association, such channel server applications include Virtual Ethernet switch (provides channel server endpoints for network channels) and virtual storage switch (provides channel server endpoints for storage channels). Unused memory and I/O resources are owned by a special 'Available' pseudo partition (not shown in figures). One such "Available" pseudo partition per node of host computing system **10** owns all resources available for allocation, and as such is tracked by resource database **33**.

[0045] In the embodiments discussed herein, control partition **14** concentrates on server input/output requirements. Plug and Play operating systems function with appropriate virtual port/miniport drivers installed as boot time drivers. The hypervisor system call interface **32** may, in some embodiments, include an Extensible Firmware Interface (EFI) to provide a modern maintainable firmware environment that is used as the basis for the virtual firmware. The firmware provides standard mechanisms to access virtual Advanced Configuration and Power Interface (ACPI) tables. These tables allow operating systems to use standard mechanisms to discover and interact with the virtual hardware.

[0046] The boot partition **12** may provide certain Basic Input/Output System (BIOS) compatibility drivers if and when necessary to enable boot of operating systems that lack EFI loaders. The boot partition **12** also may provide limited support for these operating systems.

[0047] Different partitions may use different firmware implementations or different firmware versions. The firmware identified by partition policy is loaded when the partition is activated. During an upgrade of the monitor associated with the control partition, running partitions continue to use the loaded firmware, and may switch to a new version as determined by the effective partition policy the next time the partition is reactivated.

[0048] As noted above, monitors **36** provide enforcement of isolation from other partitions. The monitors **36** run at the most privileged processor level, and each partition has one or more monitors mapped into privileged address space. Each monitor **36** uses protection exceptions as necessary to monitor software within the virtual partition and to thwart any (inadvertent) attempt to reference resources not assigned to the associated virtual partition. Each monitor **36** constrains the guest OS and applications in the guest partitions **26**, **28**, and the lead monitor **34** constrains the resource management application in the control partition **14** and uses its access and special hypervisor system call interface **32** with the resource management application to communicate individual. partition resource lists with the associated partition monitors **36**.

[0049] According to some embodiments, there are two main categories of partitions in the virtualization system of the present disclosure. The 'user' partitions run guest operating systems for customer applications, and the system infrastructure partitions provide various platform infrastructure services. For reliability, the virtualization system architecture minimizes any implementation that is not contained within a partition, since a failure in one partition can be contained and need not impact other partitions.

[0050] As will be explained in more detail below, system partition, or service partition, types can include:

[0051] Boot **12**

[0052] Idle **13**

[0053] Control **14**

[0054] Command **20**

[0055] Operations **22**

[0056] I/O **16**, **18**

[0057] Interconnect **24**

[0058] Each of these types is briefly discussed below.

[0059] Boot Partition **12**

[0060] The boot partition **12** has assigned thereto one virtual CPU (corresponding to a physical processing core or a fractional/timeshared part thereof), and contains the hardware partition boot firmware. It is used during recovery operations when necessary to boot and reboot the command partition **20** and the I/O partitions **16**, **18**. During bootstrap, the boot partition **12** reserves available memory and constructs the control partition **14** and the initial resource map in resource database **33** with all memory assigned either to the boot partition **12**, the control partition **14**, or the 'available' partition. The boot partition **12** initiates transactions to the resource manager application until it has also booted the command partition **20**. At this point the control partition **14** is attached to the command partition **20** and accepts only its command transactions. The boot partition boot processor also initializes all additional processors to run the idle partition **13**.

[0061] Idle Partition **13**

[0062] In example embodiments, the idle partition **13** has one virtual CPU for each physical CPU. These virtual CPUs are used as place holders in the system's CPU schedule. If the control partition **14** or partition monitor **34** error recovery must remove a CPU/partition from the schedule, it is replaced with a reference to one of these virtual CPUs. Idle processors 'run' in the idle partition **13**, rather than the control partition **14**, to reduce the scope of error recovery should a hardware error occur while a hardware processor is idle. In actuality, the idle partition suspends a processor (to reduce power and cooling load) until the next virtual quantum interrupt. In typical scenarios, processors can be idle a significant fraction of time. The idle time is the current shared processor headroom in the hardware partition.

[0063] Control Partition **14**

[0064] The control partition **14** owns the memory that contains the resource database **33** that stores the resource allocation maps. This includes the 'fractal' map for memory, the processor schedule, and mapped I/O hardware devices. For Peripheral Component Interconnect (PCI) I/O hardware, this map would allocate individual PCI devices, rather than require I/O partitions **16**, **18** to enumerate a PCI bus. Different devices on the same PCI bus can be assigned to different I/O partitions **16**, **18**. A resource allocation application in the control partition **14** tracks the resources, applies transactions to the resource database **33**, and is also the server for the command and control channels. The resource allocation application runs in the control partition **14** with a minimal operating environment. All state changes for the resource manager application are performed as transactions. If a processor error occurs when one of its virtual CPUs is active, any partial transactions can be rolled back. The hypervisor system call interface **32**, which is responsible for virtual processor context switches and delivery of physical and virtual interrupts, does not write to the master resource maps managed by the application. It constrains itself to memory writes of memory associated with individual partitions and read only of the master resource maps in the resource database **33**.

[0065] It is noted that, when multiple control partitions **14** are used, an associated command partition **20** can be provided for each. This allows the resource database **33** of a large host to be (literally) partitioned and limits the size of the largest virtual partition in the host while reducing the impact of failure of a control partition **14**. Multiple control partitions **14** are recommended for (very) large host partitions, or anytime a partitioned virtualized system can contain the largest virtual partition.

[0066] Command Partition **20**

[0067] In example embodiments, the command partition **20** owns the resource allocation policy for each hardware partition **10**. The operating environment is, for example, XP embedded which provides a .NET Framework execution environment. Another possibility is, for example, Windows CE and the .NET Compact Framework.

[0068] The command partition **20** maintains a synchronized snapshot of the resource allocation map managed by the resource management application, and all changes to the map are transactions coordinated through the command channel **38** (FIG. **3**) with the control partition **14**. The resource management application implements the command channel **38** to accept transactions only from the command partition **20**.

[0069] It is noted that in a multiple host hardware partition environment, a stub command partition **20** in each host **10** could simply run in the EFI environment and use an EFI application to pipe a command channel **38** from the control partition **14**, through a network, to a shared remote command partition **20**. However, this would have an impact on both reliability and recovery times, while providing only a modest cost advantage. Multiple command partitions **20** configured for failover are also possible, especially when multiple control partitions **14** are present. Restart of a command partition **20** occurs while other partitions remain operating with current resource assignments.

[0070] In accordance with the present disclosure, only a resource service in the command partition **20** makes requests of the resource manager application in the control partition

14. This allows actual allocations to be controlled by policy. Agents representing the partitions (and domains, as described below) participate to make the actual policy decisions. The policy service provides a mechanism for autonomous management of the virtual partitions. Standard and custom agents negotiate and cooperate on the use of physical computing resources, such as processor scheduling and memory assignments, in one or more physical host partitions. There are two cooperating services. The partition resource service is an application in the command partition **20** that is tightly coupled with the control resource manager application and provides services to a higher level policy service that runs in the operations partition **22** (described below) and is tightly coupled with (i.e. implements) a persistent partition configuration database, and is a client of the resource service. The resource service also provides monitoring services for the presentation tier. The partition resource objects are tightly controlled (e.g., administrators can not install resource agents) since the system responsiveness and reliability partially depends on them. A catastrophic failure in one of these objects impacts responsiveness while the server is restarted. Recurring catastrophic failures can prevent changes to the resource allocation.

[0071] Operations Partition **22**

[0072] In some embodiments, the operations partition **22** owns the configuration policy for the domains in one or more host computing systems **10**. The operations partition **22** is also where a data center operations (policy) service runs. As will be explained below, at least one host computing system **10** in a given virtual data center will have an operations partition **22**. Not all host computing systems **10** run an operations partition **22**. An operations partition **22** may be provided by multiple hosts in a virtual data center for load balancing and failover. The operations partition **22** does not need to run within a given hardware partition, and need not run as a virtual partition. The operating environment within the operations partition **22** can be, for example, MICROSOFT WINDOWS XP Professional or Windows Server, or analogous operating environments. This partition (cluster) can be shared across multiple hardware partitions. The configuration policy objects and .ASP.NET user interface components run in the operations partition **22**. These components can share a virtual partition with the command partition **20** to reduce cost for single host deployments.

[0073] For availability reasons, customization of partition resource agents is discouraged in favor of customization of policy agents. This is because a failure in a policy agent has less impact than a resource agent to the availability and responsiveness of the resource mechanisms. The policy agents make requests of the standard resource agents. The standard policy agents can also be extended with custom implementations. In simple single hardware partition installations, the services of the operations partition **22** can be hosted in the command partition **20**.

[0074] The partition definition/configuration objects are intended to be a purpose of customization. The partition policy objects are clients of the resource objects. The policy service provides configuration services for the presentation tier.

[0075] The operations partition user interface components are typically integrated within the operations partition **22**. An exemplary implementation may use Hypertext Markup Language (HTML) Version 4, CSS, and Jscript. The operations partition user interface is principally a web interface implemented by an ASP.NET application that interacts with the policy service. The user interface interacts directly with the Partition Policy Service and indirectly with a partition database of the operations partition **22**.

[0076] A .NET smart client may also be provided, in the operations partition **22** to provide a rich client interface that may interact directly with the policy and resource services to present a rich view of current (enterprise) computing resources.

[0077] A resource service in the command partition **20** selects appropriate resources and creates a transaction to assign the resources to new partitions. The transaction is sent to the control partition **14** which saves transaction request to un-cached memory as a transaction audit log entry (with before and after images). The transaction is validated and applied to the resource database **33**.

[0078] An audit log tracks changes due to transactions since the last time the resource database **33** was backed up (flushed to memory), thereby allowing transactions to be rolled back without requiring the resource database **33** to be frequently flushed to memory. The successful transactions stored in the audit log since the last resource database **33** backup may be reapplied from the audit log to restart a failed partition. A resource also may be recovered that has been reserved by a completed transaction. A transaction that has not completed has reserved no resource. The audit log may be used by the resource allocation software to rollback any partially completed transaction that survived the cache. It should be noted that a transaction that has not completed would have assigned some but not all resources specified in a transaction to a partition and the rollback would undo that assignment if it survived the cache.

[0079] I/O Partitions **16**, **18**

[0080] In the embodiment shown, a plurality of I/O partitions **16**, **18** are active on a host node **10**. I/O partitions **16**, **18** allow multi-path PCI from the user partitions **26-28** and allow certain types of failures in an I/O partition **16**, **18** to be recovered transparently. All I/O hardware in host hardware partitions is mapped to the I/O partitions **16**, **18**. These partitions are typically allocated a dedicated processor to minimize latency and allow interrupt affinity with limited overhead to pend interrupts that could occur when the I/O partition **16**, **18** is not the current context. The configuration for the I/O partitions **16**, **18** determines whether the storage, network, and console components share virtual partitions or run in separate virtual partitions.

[0081] Interconnect Service Partition **24**

[0082] The interconnect service partition **24** coordinates inter-partition communication in conjunction with the control partition **14** and the command partition **20**. Generally, and as discussed. In further detail below, the interconnect service partition **24** defines and enforces policies relating to intercommunication of partitions defined in the command partition, and publishes an application programming interface (API) that acts as a command-based interconnect that provides the various guest partitions and I/O partitions **16**, **18** intercommunication capabilities.

[0083] In some embodiments, the interconnect service partition **24** defines one or more security policies for each of the partitions included on all platforms, including the platform on which it resides. The interconnect service partition **24** implements permissions defined in such security policies to ensure that partitions intercommunicate only with those other partitions to which they are allowed to communicate. To that end,

and as discussed in further detail below, the interconnect service partition **24** can define one or more security zones, each of which defining a "virtual fabric" of platforms capable of intercommunication. As such, each security zone represents a virtual network of interconnected partitions. Each virtual network defined by the interconnect service partition **24** can be configured such that partitions within the virtual fabric can intercommunicate, but partitions not included within that virtual fabric are incapable of communicating with member partitions (e.g., unless both of those partitions are part of a different virtual fabric). By defining a plurality of virtual fabrics within each system, partitions are by default ;intrusted, or closed, rather than trusted, or open. That is, in the absence of defined virtual fabrics, the partitions are assumed able to intercommunicate. However, with defined virtual fabrics, only those partitions defined as part of a common virtual fabric will intercommunicate, with partitions otherwise, by default, unable to communicate.

[0084] In addition, the interconnect service partition **24** defines one or more rights assignable to each virtual fabric by way of the security policy, thereby allowing each virtual fabric to have assigned a variety of types of rights or services to each partition or virtual fabric. As farther discussed below, virtual fabrics including one or more guest partitions **26**, **28** can be constructed in which a particular quality of service (e.g., reliability, uptime, or dedicated levels of processing and/or memory and/or bandwidth resources) is associated with a particular virtual fabric. To ensure such service uptime, one or more different or redundant partitions can be dynamically added to or subtracted from the virtual fabric.

[0085] User Partitions **26-28**

[0086] The user partitions **26**, **28** host the workloads that form the purpose of the virtualization system, and are described in normal domains for a user. These are the partitions that a user primarily interacts with. All of the other partition types are described in the system domains and are generally kept out of view of typical users.

[0087] System Startup

[0088] When the host computing system **10** is booted, the EFI firmware is loaded first. The EFI firmware boots the operating system associated with the control partition **14**. The EFI firmware uses a standard mechanism to pick the boot target. Assuming the loader is configured and selected, boot proceeds as follows.

[0089] The loader allocates almost all of available memory to prevent its use by the firmware. (It leaves a small pool to allow proper operation of the firmware.) The loader then creates the resource database's memory data structures in the allocated memory (which includes a boot command channel predefined in these initial data structures). The loader then uses the EFI executable image loader to load the control monitor **34** and monitoring application into the control partition **14**. The loader also jacks the boot monitor underneath the boot partition **12** at some point before the boot loader is finished.

[0090] The loader the creates transactions to create the I/O partition **16** and command partition **20**. These special boot partitions are loaded from special replicas of the master partition definitions. The command partition **20** updates these replicas as necessary. The boot loader loads the monitor, and firmware into the new partitions. At this point, the boot loader transfers boot path hardware ownership from the boot firmware to the I/O partition **16**. The I/O partition **16** begins running and is ready to process I/O requests.

[0091] The loader creates transactions to create a storage channel from the command partition **20** to an I/O partition **16**, and a command channel **38** from the command partition **20** to the control partition **14**. At this point the boot loader sends a final command to the control partition **14** to relinquish the command channel **38** and pass control to the command partition **20**. The command partition **20** begins running and is ready to initialize the resource service.

[0092] The command partition operating environment is loaded from the boot volume through the boot storage channel path. The operating environment loads the command partition's resource service application. The resource service takes ownership of the command channel **38** and obtains a snapshot of the resources from the control partition's resource database **33**.

[0093] A fragment of the policy service is also running in the command partition **20**. This fragment contains a replica of the infrastructure partitions assigned to this host. The policy service connects to the resource service and requests that the 'boot' partitions are started first. The resource service identifies the already running partitions. By this time, the virtual boot partition **12** is isolated and no longer running at the most privileged processor level. The virtual boot partition **12** can now connect to the I/O partition **16** as preparation to reboot the command partition **20**. If all I/O partitions should fail, the virtual boot partition **12** also can connect to the control partition **14** and re-obtain the boot storage hardware. This is used to reboot the first I/O partition **16**.

[0094] The boot partition **12** remains running to reboot the I/O and command partitions **16**, **20** should they fail during operation. The control partition **14** implements watchdog timers to detect failures in these (as well as any other) partitions. The policy service then activates other infrastructure partitions as dictated by the current policy. This would typically start the redundant I/O partition **18**.

[0095] If the present host computing system **10** is a host of an operations partition **22**, operations partition **22** is also started at this time. The command partition **20** then listens for requests from the distributed operations partitions. As will be explained below, the operations partition **22** connects to command partitions **20** in this and other hosts through a network channel and network zone. In a simple single host implementation, an internal network can be used for this connection. At this point, the distributed operations partitions **22** start the remaining partitions as the current policy dictates.

[0096] All available (not allocated) memory resources are owned by the special 'available' partition. In the example of FIGS. **1** and **2**, the available partition is size is zero and thus is not visible.

[0097] Referring to FIG. **3**, virtual channels are the mechanism partitions use in accordance with the invention to connect to zones and to provide fast, safe, recoverable communications amongst the partitions. For example, virtual channels provide a mechanism for general I/O and special purpose client/server data communication between guest partitions **26**, **28** and the I/O partitions **16**, **18** in the same host. Each virtual channel provides a command and I/O queue (e.g., a page of shared memory) between two partitions. The memory for a channel is allocated and 'owned' by the guest partition **26**, **28**. These queues are discussed in further detail below in connection with the interconnect Application Programming Interface (API) as illustrated in FIGS. **6-9**. The control partition **14** maps the channel portion of client memory into the virtual memory space of the attached server

partition. The control application tracks channels with active servers to protect memory during teardown of the owner guest partition until after the server partition is disconnected from each channel. Virtual channels can be used for command control, and boot mechanisms as well as for traditional network and storage I/O.

[0098] As shown in FIG. **3**, the control partition **14** has a channel server **40** that communicates with a channel client **42** of the command partition **20** to create the command channel **38**. The I/O partitions **16**, **18** also include channel servers **44** for each of the virtual devices accessible by channel clients **46**, such as in the operations partition **22**, interconnect service partition **24**, and one or all guest partitions **26**, **28**. Within each guest virtual partition **26**, **28**, a channel bus driver enumerates the virtual devices, where each virtual device is a client of a virtual channel. The dotted lines in I/O partition **16** represent the interconnects of memory channels from the command partition **20** and operations partitions **22** to the virtual Ethernet switch in the I/O partition **16** that may also provide a physical connection to the appropriate network zone. The dotted lines in I/O partition **18** represent the interconnections to a virtual storage switch. Redundant connections to the virtual Ethernet switch and virtual storage switches are not shown in FIG. **3**. A dotted line in the control partition **14** from the command channel server **40** to the transactional resource database **33** shows the command channel connection to the transactional resource database **33**.

[0099] A firmware channel bus (not shown) enumerates virtual boot devices. A separate bus driver tailored to the operating system enumerates these boot devices as well as runtime only devices. Except for I/O virtual partitions **16**, **18**, no PCI bus is present in the virtual partitions. This reduces complexity and increases the reliability of all other virtual partitions.

[0100] Virtual device drivers manage each virtual device. Virtual firmware implementations are provided for the boot devices, and operating system drivers are provided for runtime devices. The device drivers convert device requests into channel commands appropriate for the virtual device type.

[0101] Additional details regarding possible implementation details of a partitioned, para-virtualization system, including discussion of multiple are discussed in U.S. Pat. No. 7,984,104, assigned to Unisys Corporation of Blue Bell, Pa., the disclosure of which is hereby incorporated by reference in its entirety. Other example partitioning mechanisms, and additional details regarding partitioning within such a computing arrangement, are described in copending U.S. patent application Ser. No. 11/133,803, entitled "INTERCONNECT PARTITION BINDING API, ALLOCATION AND MANAGEMENT OF APPLICATION-SPECIFIC PARTITIONS" (Attorney Docket No. TN587A), the disclosure of which is hereby incorporated by reference in its entirety.

II. Computing Systems Used to Establish SR-IOV Functionality

[0102] Referring now to FIGS. **4-5**, example arrangements of computing resources are illustrated for establishing a para-virtualization system across a plurality of host computing systems, such as host computing system s **10** of FIGS. **1-3**, are shown. In particular, FIGS. **4-5** illustrate example computing resources in which the para-virtualization systems described herein can be implemented.

[0103] As illustrated in FIG. **4**, a system **100** in which the para-virtualization systems of the present disclosure can be implemented is shown. The system **100** is, in the embodiment shown, distributed across one or more locations **102**, shown as locations **102***a-c*. These can correspond to locations remote from each other, such as a data center owned or controlled by an organization, a third-party managed computing cluster used in a "cloud" computing arrangement, or other local or remote computing resources residing within a trusted grouping. In the embodiment shown, the locations **102***a-c* each include one or more host systems **104**. The host systems **104** represent host computing systems, and can take any of a number of forms. For example, the host systems **104** can be server computing systems having one or more processing cores and memory subsystems and are useable for large-scale computing tasks. In one example embodiment, a host system **104** can be as illustrated in FIG. **5**.

[0104] As illustrated in FIG. **4**, a location **102** within the system **100** can be organized in a variety of ways. In the embodiment shown, a first location **102***a* includes network routing equipment **106**, which routes communication traffic among the various hosts **104**, for example in a switched network configuration. Second location **102***b* illustrates a peer-to-peer arrangement of host systems. Third location **102***c* illustrates a ring arrangement in which messages and/or data can be passed among the host computing systems themselves, which provide the routing of messages. Other types of networked arrangements could be used as well.

[0105] In various embodiments, at each location **102**, the host systems **104** are interconnected by a high-speed, high-bandwidth interconnect, thereby minimizing latency due to data transfers between host systems. In an example embodiment, the interconnect can be provided by an Infiniband switched fabric communications link; in alternative embodiments, other types of interconnect technologies, such as Fibre Channel, PCI Express, Serial ATA, or other interconnect could be used as well.

[0106] Among the locations **102***a-c*, a variety of communication technologies can also be used to provide communicative connections of host systems **104** at different locations. For example, a packet-switched networking arrangement, such as via the Internet **108**, could be used. Preferably, the interconnections among locations **102***a-c* are provided on a high-bandwidth connection, such as a fiber optic communication connection.

[0107] In the embodiment shown, the various host system **104** at locations **102***a-c* can be accessed by a client computing system **110**. The client computing system can be any of a variety of desktop or mobile computing systems, such as a desktop, laptop, tablet, smartphone, or other type of user computing system. In alternative embodiments, the client computing system I/O can correspond to a server not forming a cooperative part of the para-virtualization system described herein, but rather which accesses data hosted on such a system. It is of course noted that various virtualized partitions within a para-virtualization system could also host applications accessible to a user and correspond to client systems as well.

[0108] It is noted that, in various embodiments, different arrangements of host systems **104** within the overall system **100** can be used; for example, different host systems **104** may have different numbers or types of processing cores, and different capacity and type of memory and/or caching subsystems could be implemented in different ones of the host

system **104**. Furthermore, one or more different types of communicative interconnect technologies might be used in the different locations **102***a-c*, or within a particular location.

[0109] Referring to FIG. **5**, an example block diagram of a host computing system **200** useable to implement the para-virtualization systems of FIGS. **1-3**, is shown. The host computing system **200** can, in some embodiments, represent an example of a host system **104** of FIG. **4**, useable within the system **100**. The host computing system **200** includes one or more processing subsystems **202**, communicatively connected to a system memory **204**. Each processing subsystem **202** can include one or more processing cores **206**, shown as processing cores **206***a-n*. Each processing core can, in various embodiments, include one or more physical or logical processing units capable of executing computer-readable instructions. In example embodiments, the processing cores **206***a-n* can be implemented using any of a variety of x86 instruction sets, such as x86, x86-64, or IA64 instruction set architectures. In alternative embodiments, other instruction set architectures, such as ARM, MIPS, Power, SPARC, or other types of computing set architectures could be used.

[0110] In addition, each of the processing subsystems **202** can include one or more card-based processing subsystems including a plurality of sockets for supporting execution cores **206***a-n*, or alternatively can support a socket-based or mounted arrangement in which one or more execution cores are included on a single die to be mounted within the host computing system **200**. Furthermore, in the embodiment shown, a plurality of processing subsystems **202** can be included in the host computing system, thereby providing a system in which one or more cores could be allocated to different partitions hosted by the same computing hardware; in alternative embodiments, a single processing subsystem including one or more processing cores **206***a-n* could be included in the host computing system **200**, and that processing subsystem **202** could be implemented without separation from system memory **204** by a card-based implementation.

[0111] As illustrated, the system memory **204** is communicatively interconnected to the one or more processing subsystems **202** by way of a system bus **205**. The system bus is largely dependent upon the architecture and memory speed support of the processing subsystems with which it is implemented; although example systems provide different frequencies and throughputs of such system buses, in general the bus system between processing subsystems **202** and the system memory is a low-latency, high bandwidth connection useable to rapidly retrieve data from the system memory **204**. System memory **204** includes one or more computer storage media capable of storing data and/or instructions in a manner that provides for quick retrieval of such data and/or instructions by a corresponding processing core **206**. In different embodiments, the system memory **204** is implemented in different ways. For example, the memory **204** can be implemented using various types of computer storage media.

[0112] In the embodiment shown, system memory **204** can be allocated to one or more partitions using the software described herein. In the example illustration shown, subsections of the system memory **204** can be allocated to a control partition section **210** and one or more memory partitions **212**. The control partition section **210** includes a monitor **211**, which in some embodiments can represent monitor **34**. The control partition section **210** can also include a resource database **214** that tracks resources allocated to other partitions within the host computing system **200**. This can include, for example, a listing of execution cores **206**, capacity and location of system memory **204**, as well as I/O devices or other types of devices associated with each partition. In example embodiments, the resource database **214** can correspond to database **33** of FIGS. **1-3**.

[0113] In the embodiment shown, the system memory **204** includes memory partitions **212** which each are associated with different partitions formed within a host computing system **200**. The memory partitions **212** can, in the embodiment shown, each include a monitor **216**, an associated operating system **218**, and one or more applications or workloads **220** to be executed within the partition. Since each memory partition **212** can be associated with one or more execution cores **206** in the resource database **214**, the assigned execution cores can be used to access and execute the monitor software **216** as well as the operating system **218** and workloads **220**.

[0114] It is noted that in some embodiments, the partition **212** may include multiple instances of the monitor software **216**. This may be the case, for example, for partitions that have allocated thereto more than one execution core. For such cases, monitor software **216** may be a located for and used with each execution core. Therefore, there may be more than one such monitor executing per partition, with each monitor handling various I/O, memory, or interrupt servicing tasks that may be issued with respect to that particular execution core. Each monitor supervises execution of software within a partition as allocated to a particular execution n core; accordingly, if a single partition has multiple execution cores, the operating system **218** may allocate execution of operating system tasks, or the workload(s) **220**, to one or both of the execution cores. The host computing device includes an I/O subsystem **222** that includes one or more input devices **224**, output devices **226**, and storage devices **228**. The input devices **224** can include, for example, a keyboard, a mouse, a pen, a sound input device, a touch input device, etc. Output device(s) **226** can include, for example, a display, speakers, a printer, etc. The aforementioned devices are examples and others may be used. Storage devices **228** store data and software instructions not directly accessible by the processing subsystems **202**. In other words, the processing subsystems **202** perform an I/O operation to retrieve data and/or software instructions from the storage device **228**. In various embodiments, the secondary storage device **228** includes various types of computer storage media. For example, the secondary storage device **228** can include one or more magnetic disks, magnetic tape drives, optical discs, solid state memory devices, and/or other types of computer storage media.

[0115] The I/O subsystem **222** further includes one or more communication connections **230**. The communication connections **230** enable the computing device **1000** to send data to and receive data from a network of one or more such devices. In different embodiments, the communication connections can be implemented in different ways. For example, the communications connections can include a network interface card implementing an Ethernet interface, a token-ring network interface, a fiber optic network interface, a wireless network interface (e.g., Wi-Fi, WiMax, etc.), or another type of network interface. The communication connections **232** can also include an inter-system communication connection for direct data communication between computing systems, such as a Infiniband switched fabric communications link, or a Fibre Channel, PCI Express, Serial ATA, or other type of direct data communication link.

[0116] It is noted that, in some embodiments of the present disclosure, other arrangements of a partition may be included as well, providing various allocations of execution cores **206**, system memory **204**, and I/O devices **224**, **226** within the I/O subsystem **222**. For example, a partition may include zero or more execution cores **206**; in the event that no processor is included with the partition, the partition may lack a monitor **216**, and may instead of having an executable operating system **218** may instead include a library of commands accessible to one or more services partitions, for example useable to provide I/O or memory services to those other service partitions. Furthermore, a particular partition could be allocated access to a storage device **228** or communication connections **230**.

[0117] It is noted that in the present embodiment an interconnect service partition **250** and a trusted code section **260** maintained in the system memory **204**. The interconnect service partition **250** maintains a monitor **251** providing virtualization services. The interconnect service partition **250** and trusted code section **260**, described in further detail below in connection with FIGS. **6-11**, host a single-root PCI manager (SR-PCIM) **252** which manages I/O device drivers used for virtualization of I/O devices across guest partitions located in partitioned memory **212**.

[0118] It is noted that, in typical hypervisor arrangements, failures occurring in one execution core allocated to the partition result in failure of the partition overall, since the failure results in failure of the monitor associated with the partition. In connection with the present disclosure, partitions including multiple monitors can potentially recover from such failures by restarting the execution core and associated monitor using the remaining, correctly-executing monitor and execution core. Accordingly, the partition need not fail.

[0119] As used in this document, a computer storage medium is a device or article of manufacture that stores data and/or computer-executable instructions. Computer storage media may include volatile and nonvolatile, removable and non-removable devices or articles of manufacture implemented in any method or technology for storage of information, such as computer readable instructions, data structures, program modules, or other data. By way of example, and not limitation, computer storage media may include dynamic random access memory (DRAM), double data rate synchronous dynamic random access memory (DDR SDRAM), reduced latency DRAM, DDR2 SDRAM, DDR3 SDRAM, DDR4 SDRAM, solid state memory, read-only memory (ROM), electrically-erasable programmable ROM, optical discs (e.g., CD-ROMs, DVDs, etc.), magnetic disks (e.g., hard disks, floppy disks, etc.), magnetic tapes, and other types of devices and/or articles of manufacture that store data. Computer storage media generally includes at least some tangible, non-transitory media and can, in some embodiments, exclude transitory wired or wireless signals. Communication media may be embodied by computer readable instructions, data structures, program modules, or other data in a modulated data signal, such as a carrier wave or other transport mechanism, and includes any information delivery media. The term "modulated data signal" may describe a signal that has one or more characteristics set or changed in such a mariner as to encode information in the signal. By way of example, and not limitation, communication media may include wired media such as a wired network or direct-wired connection, and wireless media such as Wi-Fi, acoustic, radio frequency (RF), infrared, and other wireless media. In accordance with the present disclosure, the term computer readable media as used herein may include computer storage media, but generally excludes entirely transitory embodiments of communication media, such as modulated data signals.

[0120] Furthermore, embodiments of the present disclosure may be practiced in an electrical circuit comprising discrete electronic elements, packaged or integrated electronic chips containing logic gates, a circuit utilizing a microprocessor, or on a single chip containing electronic elements or microprocessors. For example, embodiments of the invention may be practiced via a system-on-a-chip (SOC) where each or many of the components illustrated in FIGS. **4-5** may be integrated onto a single integrated circuit. Such an SOC device may include one or more processing units, graphics units, communications units, system virtualization units and various application functionality all of which are integrated (or "burned") onto the chip substrate as a single integrated circuit. Embodiments of the invention may also be practiced using other technologies capable of performing logical operations such as, for example, AND, OR, and NOT, including but not limited to mechanical, optical, fluidic, and quantum technologies, in addition, embodiments of the invention may be practiced within a general purpose computer or in any other circuits or systems.

[0121] Although particular features are discussed herein as included within a host computing system **200**, it is recognized that in certain embodiments not all such components or features may be included within a computing device executing according to the methods and systems of the present disclosure. Furthermore, different types of hardware and/or software systems could be incorporated into such an electronic computing device,

III. SR-IOV Management and Operation

[0122] Referring now to FIGS. **6-11**, details regarding implementation of a single-root I/O virtualization (SR-IOV) implementation that presents such I/O devices and manages PCI devices in a partition or virtual machine (rather than in the virtualization software itself) are illustrated. As briefly described above, the implementations provided in FIGS. **6-11** allow for redundancy and failover of not only virtual functions in an SR-IOV framework, but fault tolerance in the physical function and single root PCI manager (SR-PCIM). The system also allows the SR-PCIM to be able to determine the contents of ECAM memory that is otherwise stored in a privileged location not typically accessible to software executing within a virtualized partition.

[0123] Referring first to FIG. **6**, an example multi-partition environment **600** in which aspects of the present disclosure can be embodied is discussed. In the environment **600** as shown, an interconnect service partition **602**, as well as a plurality of guest partitions **604** and a plurality of I/O service partitions **606** are shown, alongside trusted code base (TCB) **608**, each executing on a hardware layer **610**. It is noted that other partitions or partition types can and typically will be executing on the hardware layer as well, for example as discussed above in connection with FIGS. **1-3** (e.g., the boot partition, idle partition, and other service partitions discussed therein). Each of the interconnect service partition **602**, guest partitions **604**, and I/O service partitions **606** generally perform the functions as discussed above in FIG. **103** with respect to correspondingly-named partitions. In addition a trusted code base **608** can be used to perform low-level,

privileged operations, and can be granted access at a very high privilege level maximizing its right to view/modify system memory).

[0124] Furthermore, the hardware layer **610** generally includes one or more processing cores **612**, I/O devices **614**, and a memory **616**. The hardware layer **610** can be implemented in any manner suitable for use within a distributed multi-partition system, for example in the same or different host systems. Any such host system as described above in connection with FIGS. **4-5** would be suitable, in connection with the present disclosure.

[0125] In the embodiment shown in FIG. **6**, each of the interconnect service partition **602**, guest partitions **604**, and I/O service partitions **606** include a monitor **601** operating as virtualization software. Each also has a virtual BIOS, shown as BIOS **603**, that allows for booting into an operating system of that partition, such as a Guest OS **605**, or in the case of the interconnect service partition **602**, optionally instead a collection of interconnect services **607**.

[0126] In the embodiment shown, the I/O devices **614** in the hardware layer **610** include at least one SR-IOV-compliant device capable of being mapped from one physical function to a plurality of virtual functions. Accordingly an I/O configuration space **617** is included within memory **616**, and includes I/O configuration memory settings, for example defining mappings between physical and virtual functions of one or more SR-IOV compliant devices. Example memory arrangements for the I/O configuration space **617** are provided in the Single Root I/O Virtualization and Sharing Specification, Revision 1.1, dated Jan. 20, 2010, the contents of which are hereby incorporated by reference in their entirety.

[0127] In the embodiment shown, the interconnect service partition **602** is configured to manage SR-IOV devices by maintaining the physical functions, while virtual functions are distributed among partitions intended as users of particular I/O device functionality. For example, one physical function may be assigned to an interconnect service partition and may be associated with one I/O service partition **606**, and two or more guest partitions **604**. Alternative arrangements in which virtual functions are assigned to different numbers or types of partitions are possible as well, and only depend on the selected configuration of the partitions, as is apparent herein,

[0128] In the embodiment shown, a single root PCI manager application (SR-PCIM) **620** is maintained partially within the interconnect service partition **602**, as well as within the trusted code block **608**. The SR-PCIM **620** manages configuration of the physical function and virtual functions associated with each SR-IOV-compliant I/O device. In particular, SR-PCIM is the software responsible for the configuration of the SR-IOV capability, processing of associated error events and overall device controls such as power management and hot-plug services for physical and virtual functions,

[0129] In the embodiment shown, the SR-PCIM **620** manages storage of a physical function driver **622** associated with a physical function of an I/O device (e.g., one of I/O devices **614**), and tracks an association of that physical function to virtual functions included in other partitions, such as guest partitions **604** and I/O service partitions **606**. The physical function driver **622** defines the interface useable by software to access functionality of the I/O device associated with that driver, which is made available via virtual function drivers **624** present in other partitions and which can be loaded by the operating systems of those other partitions to access the I/O device(s) **614**.

[0130] In example embodiments, the physical function driver **622** is generally a Linux-compliant device driver useable in connection with a SR-IOV-compliant device. However, in some embodiments, the physical function driver **622** can be modified to directly read from the **110** configuration space **617**.

[0131] Because the SR-PCIM **620** is to a large extent a trusted code block, it as such at least partially resides in domain 0 on the host where it resides (e.g., within the trusted code base **608**). Furthermore, the SR-PCIM manages the extent to which the interconnect service partition **602** is allowed to do using the physical function driver **622**. In example embodiments, monitors **601** associated with other partitions, such as the interconnect service partition **602**, guest partition **604**, or I/O service partition **606** can each also be included in a trusted code base and given domain 0, or root access, to the hardware on the host system. Accordingly, various SR-IOV functions can be distributed between the trusted code base **608** and the various monitors **601** as may be advantageous in different embodiments.

[0132] In the embodiment shown, the trusted code base **608** further includes a configuration file **626**, shown as an XML file. The configuration file **626** stores information defining mappings between hardware devices and physical functions, including physical function drivers, as well as mappings between the physical functions and associated virtual functions for SR-IOV compliant devices. In example embodiments, the configuration file **626** also stores status information regarding each physical I/O device, physical function, and virtual function, for example to determine whether each is active, functional, or in an error state, in example embodiments, the configuration file **626** is representative of contents of the I/O configuration space **617**, but are stored such that software systems that do not require access rights to privileged memory can access and modify the file. Modifications to the configuration file **626** are then monitored and propagated to the I/O configuration space **617** by the trusted code base **608**.

[0133] In some embodiments, the trusted code base **608** and/or SR-PCIM **620** implements a Translation Agent (TA), which corresponds to a combination of hardware and software responsible for translating an address within a PCIe transaction into the associated platform physical address. A TA may contain an Address Translation Cache (ATC) to accelerate translation table access. A TA may also support the PCI-SIG Address Translation Services Specification Which enables a PCIe function to obtain address translations a priori to DMA access to the associated memory.

[0134] Referring to FIG. **7**, an example correspondence between a configuration file **626** and an I/O configuration space **617** is shown. In the example shown, an XML file includes a plurality of device entries. The device entries each are associated with a different I/O device having a separate configuration memory space in the I/O configuration space **617**. For example, a first entry, associated with a first I/O device, may correspond to a first physical function configuration space for that same I/O device, while a second entry in the XML file **626** may be associated with a second physical function configuration space, and so on.

[0135] As shown in FIG. **7**, each of the device entries is associated with an I/O device, and as such is associated with

a device driver used by system software to access and address the device. The device entries of the XML file **626** includes a status (e.g., active, inactive, error states), as well as a plurality of defined mappings to virtual functions. Each of the plurality of virtual functions can be assigned to different partitions and can also have a status associated therewith. For example, although a physical function may be active, a partition associated with one of the virtual functions may be in the process of rebooting, so that virtual function may be inactive. Other permutations on status of the physical and virtual functions are possible as well.

[0136] It is noted that, for each of the entries in the XML file **626**, corresponding data is available in the I/O configuration space **617** (also known as ECAM memory in some embodiments). In example embodiments, a configuration space for a particular I/O device may include a device ID and vendor ID, base address registers, expansion ROM addresses, a capabilities pointer, as well as an SR-IOV extended capabilities space. The SR-IOV extended capabilities space can include, for example, SR-IOV capabilities data, as veil as a status memory area, control bits, stride/offset data, as well as virtual function mappings via VFBAR memory areas that define a mapping of (in this case) up to eight virtual functions for each physical function. Details regarding the I/O configuration space **617** are provided in the Single Root I/O Virtualization and Sharing Specification, Revision 1.1, dated Jan. 20, 2010, the contents of which were previously incorporated by reference in their entirety.

[0137] Referring now to FIG. **8**, an example flowchart of a method **800** by which an SR-IOV device can be instantiated within a multi-partition framework such as that shown in connection with FIGS. **1-3** and **6** is provided. Aspects of the method **800** can be performed, for example, by a virtualization system, such as an interconnect service partition and/or a guest or I/O service partition, depending on the implementation and intended mapping of virtual functions within the multi-partition framework.

[0138] In the example shown, the method **800** includes a physical function operation **802** that operates to store a physical function driver in an interconnect service partition. The physical function operation **802** can be performed by a SR-IOM in the interconnect service partition, and can include loading of a physical function driver.

[0139] A guest partition initiation operation **804** includes a BIOS loading process that is initiated in the guest partition that will be associated with one of the virtual functions. During this BIOS loading process, base address registers are allocated during a partition boot, in operation **806**. A parse operation **808** can include the SR-IOM of the interconnect service partition reading a file (e.g., XML file **626**) defining the configuration information that is provided in the I/O configuration space (e.g., I/O configuration space **617**) to determine mappings between the physical function and one or more virtual functions (including a virtual function to be mapped to the guest partition being booted.

[0140] Based on the SR-PCIM determining that the partition being booted is associated with one of the virtual functions for one or more devices the SR-IOM will perform an activate operation **810** to activate the VFs for those guest partitions by writing to the XML file **626**, which is propagated to the I/O configuration memory space by the trusted code block **808**. Accordingly, the guest partition or I/O service partition can complete a boot operation **812**, and boot into an operating system, thereby loading the virtual function associated with each device that is mapped for use by that partition in the I/O configuration space and XML file. Based on that loading process, the virtual function appears during the boot operation and can be accessed by the operating system, which views the virtual function equivalently to a physical I/O device.

[0141] Referring to FIG. **9**, an example method **900** for booting a guest or I/O service partition that is associated with a virtual function is illustrated. The method **900** can be performed, for example, concurrently with operations **804-808** performed by the SR-PCIM in the interconnect service partition.

[0142] In the example embodiment shown, the method **900** includes an initialization operation **902**, which corresponds to initialization of the partition that is to be associated with one or more virtual functions. It is noted that, in example implementations of the present disclosure, such a partition to which a virtual function is to be assigned may have a variety of startup states. Such states can include, for example, an Enabled state, an Active state, an Alive state, a ChannelsAssigned state, a ProcessorAssigned state, a MemoryAssigned state, a ProcessorsAttached state, a ProcessorsScheduled state a ChannelsAttached state, a ChannelsScheduled state, a MemoryImage, ChannelImage, and ProcessorImage states, a ProcessorsOperating state, and a ChannelsOperating state, each indicating different operative states of various components of the system. It is noted that, in such cases, until processors are attached and scheduled for execution, the partition cannot initiate execution of workloads. In the context of the present disclosure, initialization can correspond to preparing the partition by assigning channels, processor(s), and memory to the partition, but not yet attaching or scheduling processors, thereby preventing initialization of operation until the virtual functions and associated physical function are verified as operational and associated with the partition.

[0143] After the partition is initialized, it is determined which virtual functions are to be associated with that partition, in operation **904**. This can result in a determination that one or more virtual functions are to be associated with the partition, thereby appearing as I/O devices to the operating system hosted within that partition.

[0144] The method determines whether a physical function associated with the virtual function is in a ready state, based on assessment operation **906**. This can correspond, for example, to an SR-PCIM within an interconnect service partition determining that, based on the contents of a file representing an I/O configuration memory space (e.g., XML file **626**), a physical function associated with each of the virtual functions to be mapped to the partition to be initialized is active (e.g., in a "ready" state).

[0145] If the physical function is not in a ready state, the method **900** may enter a wait state **907** to allow the physical function to enter a ready state, for example in the case that the interconnect service partition is concurrently being initialized or the SR-PCIM had to re-initialize the physical function recently. In example embodiments, the wait state **607** can be accomplished by looping on an attaching processor state (e.g., prior to ProcessorsAttached in the above set of states), thereby preventing the guest partition that is to be allocated a virtual function from running (since no processor is attached and associated with that guest partition). After the wait state **907**, a further assessment operation **908** determines whether the physical function is in a ready state, based on a device descriptor associated with that physical function. If, after

waiting a predetermined amount of time, the physical function is not in the ready state, one or more actions may be taken. For example, in one example embodiment, the SR-PCIM in the interconnect service partition may attempt to restart the physical function or reinstate the physical function driver. In another example embodiment, the interconnect service partition can restart the SR-PCIM, which may result in a re-reading of the XML file, which may be updated based on changed I/O configuration data (e.g., in the I/O configuration space **617**, such as ECAM memory). In a further example embodiment, the interconnect service partition in which the SR-PCIM and physical function driver can be restarted altogether, which will result in re-initialization of the physical function, as well as reloading of the physical function driver and SR-PCIM. This can include setting an UltraDeviceDescriptor for the physical function.

[0146] If the physical function is in a ready state after the wait state **907**, or if the physical function is in a ready state initially, the method continues to a processor attach operation **910**, which attaches a processor to the partition, it is noted that, although the physical function may be ready, the interconnect service partition may still be booting through other states (as noted above); however, the guest partition that is loading a virtual function associated with the ready physical function need not wait for the interconnect service partition to complete booting before proceeding. Accordingly, by associating a processor with the partition that is being initialized, the partition can initialize execution. Accordingly, an initiate execution operation **912** initiates booting of the partition through its BIOS and into its operating system, loading all virtual functions that are verified as available and associated with ready physical functions and physical function drivers.

[0147] Referring generally to FIGS. **8-9** it is apparent from these arrangements that, rather than taking an OS-specific view of allocation and assignment of virtual functions to partitions, the present disclosure contemplates managing such features from the SR-PCIM and in a dedicated partition, such as the interconnect service partition as described. This allows the presently described systems to allocate all virtual functions and associated memory in the I/O configuration space **617** prior to configuration of the virtual functions as associated with partitions themselves. This allows for dynamic addition or removal of virtual functions to/from the XML file **626**, and thereby allowing the SR-PCIM to dynamically change mappings of physical and virtual functions within the virtualization system.

[0148] FIGS. **10**A-**10**B illustrate an example arrangement by which a guest or I/O service partition can be initialized within the context of the multi-partition environment **600** of FIG. **6**, for example using the methods and systems of FIGS. **8-9** described above. In the example shown, a physical function driver **622** is loaded by SR-IOM **620**, for example during physical function operation **802** of FIG. **8**. Subsequent to the physical function driver **622** being loaded and active, a guest partition **604** or I/O service partition **606** (shown as guest partition **604**) is initialized, for example by initiating a BIOS loading process as in operation **804** of FIG. **8**. Base address registers are allocated, and a file (e.g., XML file **626**) is parsed to determine an association between a virtual function **624** to be loaded by the partition being initialized and a physical function and physical function driver **622** that is currently associated with an I/O device **614**.

[0149] Once the correspondence between the virtual function and physical function is determined (e.g., as performed in operation **904** of FIG. **9**) and assuming that the physical function is in the ready state, as shown in FIG. **10**B, the virtual function driver **624** is activated within the guest partition **604**, and a processor **614** is attached to the guest partition, allowing the guest partition to boot into the guest operating system **605**.

[0150] Referring now to FIG. **11**, a method **1100** of managing a physical function and single root PCI manager (SR-PCIM) in a partition of a multi-partition system is shown, according to an example embodiment. The method **1100** can be performed, for example, by an interconnect service partition (e.g., partition **602**) to manage a physical function and/or SR-PCIM that manages physical functions associated with I/O devices. In connection with method **1100**, it is noted that the physical function associated with a particular I/O device need not be reset when a SR-PCIM is reset; as such, a guest partition may still be able to function and use its associated virtual functions despite the SR-PCIM being inoperable for at least some period of time.

[0151] In the embodiment shown, the method **1100** includes a count operation **1102** that maintains a count of active virtual functions for each physical function. The count operation **1102** can correspond, for example to periodically reading a file, such as XML file **626**, defining each of the SR-IOV device mappings, and which is maintained by the trusted code block **608**. The method **1100** determines whether an SR-IOM reset is needed, at operation **1104**. This can be for a variety of reasons. For example, the SR-IOM may need to be reset to re-load a different physical function driver, or in the event of malfunction of either the SR-IOM or a physical function driver associated with an I/O device managed by the SR-IOM.

[0152] If no reset is required, the method **1100** simply returns to maintaining a count of active virtual functions for each physical function in the count operation. However, if a SR-PCIM reset is required, an active virtual function determination operation **1106** determines whether any active virtual functions are associated with any of the physical functions managed by the SR-PCIM. If there are active virtual functions that are associated with any of the physical functions being managed by the SR-PCIM, a reset operation **1108** can be performed in which the SR-PCIM is reset without resetting the physical functions, or at least those physical functions that are associated with active virtual functions as determined in operation **1106**.

[0153] If it is determined that there are no active virtual functions associated with any of the physical functions managed by the SR-PCIM, a reset operation **1110** is performed, which resets each of the physical functions within the SR-PCIM as well as the SR-PCIM itself, while maintaining persisted configuration memory. In other words, in the case of the arrangement **600** of FIG. **6**, the SR-PCIM **620** and physical functions maintained in the interconnect service partition **602** can be reset without causing the trusted code block **608** to alter either the XML file **626** or to alter the I/O configuration space **617** in memory **616**. When restarted, an association operation associates the maintained I/O configuration space **617** with the associated physical function.

[0154] Referring to FIG. **11** generally, it is noted that, in typical implementations of SR-IOV systems, because the SR-PCIM is configured for direct access of ECAM memory (e.g., the configuration space **617**), in such embodiments resetting the SR-PCIM will cause release of the ECAM memory, rather than preserving such settings between physical and virtual functions. Accordingly, a reset of a physical

function may in such cases require reset of each of the associated virtual functions. Furthermore, in typical implementations, the physical function is reset when the SR-PCIM is reset. According to the embodiments described herein, such resetting need not occur.

[0155] Although the present disclosure and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the disclosure as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the present invention, disclosure, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present disclosure. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

[0156] The above specification, examples and data provide a complete description of the manufacture and use of the composition of the invention. Since many embodiments of the invention can be made without departing from the spirit and scope of the invention, the invention resides in the claims hereinafter appended.

1. A method of instantiating a virtual function in a partition of a multi-partition virtualization system implemented at least in part on a computing device, the method comprising:

initializing a partition on the computing device, including determining a virtual function to be associated with the partition, the virtual function associated with a physical function of an I/O device;

prior to attaching a processor to the partition, determining if the physical function is in a ready state and capable of being associated with the virtual function; and

upon determining that the physical function is in the ready state and capable of being associated with the virtual function, attaching the processor to the partition, thereby allowing the partition to begin execution.

2. The method of claim **1**, further comprising, until determining that the physical function is in the ready state, preventing the processor from being attached to the partition, thereby preventing the partition from beginning execution.

3. The method of claim **1**, wherein the partition comprises a guest partition.

4. The method of claim **1**, further comprising, upon determining that the physical function is not in a ready state, reinstantiating the physical function within an interconnect service partition on the computing device.

5. The method of claim **4**, wherein reinstantiating the physical function comprises resetting the interconnect service partition.

6. The method of claim **4**, wherein the interconnect service partition completes initialization after the physical function is in the ready state.

7. The method of claim **1**, wherein the partition comprises an I/O service partition that manages local data storage on the computing system.

8. The method of claim **1**, wherein determining if the physical function is in :ready state comprises checking a device descriptor of the physical function.

9. A system comprising:

a first partition implemented on a computing system including a plurality of processors, memory, and at least one I/O device having an associated physical function, the physical function having a plurality of operational states including a ready state;

a second partition implemented on the computing system, the second partition capable of having at least one of the plurality of processors associated therewith to initiate execution of the second partition and having a virtual function associated with the physical function;

wherein the system is configured to determine, prior to associating the at least one of the plurality of processors therewith, whether the physical function is in at least the ready state;

wherein, if the physical function is not in at least the ready state, the system prevents association of any of the plurality of processors with the second partition.

10. The system of claim **9**, wherein preventing association of any of the plurality of processor with the second partition prevents operation of the second partition until the physical function is in at least the ready state.

11. The system of claim **9**, wherein the physical function has a plurality of states including an enabled state, an active state, an alive state, a channels assigned state, a processor assigned state, a memory assigned state, a processors attached state, a processors scheduled state, a channels attached state, a channels scheduled state, a memory image state, a channel image state, a processor image state, a processors operating state, and a channels operating state.

12. The system of claim **9**, wherein the first partition comprises an interconnect service partition, and the device comprises a communication interface.

13. The system of claim **9**, wherein the second partition comprises a guest partition.

14. The system of claim **9**, wherein the second partition comprises an I/O service partition that manages local data storage on the computing system.

15. The system of claim **9**, wherein, if the physical function is not in at least the ready state, the second partition waits in a processors-attached state until the physical function is in a ready state.

16. The system of claim **9**, wherein, upon determining that the physical function is in the ready state, the second partition continues to boot into an operating system hosted within that partition.

17. A computer readable storage medium having computer-executable instructions stored thereon, which, when executed by a computing system, cause the computing system to perform a method of instantiating a virtual function in a partition of a multi-partition virtualization system implemented at least in part on a computing device, the method comprising:

initializing a partition on the computing device, including determining a virtual function to be associated with the partition, the virtual function associated with a physical function of an I/O device of the computing system;

prior to attaching a processor to the partition, determining if the physical function is in at least a ready state;

while the physical function is not in at least the ready state, maintaining the partition in a processors attached state, thereby preventing instantiation of an operating system within the partition;

upon determining that the physical function is in at least the ready state, attaching the processor to the partition, thereby allowing the partition to begin execution.

18. The computer readable storage medium of claim **17**, wherein the physical function is managed within an interconnect service partition separate from the partition.

19. The computer readable storage medium of claim **18**, attaching the processor to the partition occurs prior to completed instantiation of the interconnect service partition.

20. The computer readable storage medium of claim **17**, wherein the partition comprises at least one of a guest partition or an I/O service partition.

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