WHITE PAPER- DECEMBER 2010

Next-Generation Pervasive Network & Software Architecture

With Routers/Switches As Virtualized Federated Servers

Sateesh Addepalli
Advanced Architecture & Research
Cisco Systems, Inc.
sateeshk@cisco.com

Bob DeAnna
Chief Technology Officer
Recursion Software
bdeanna@recursionsw.com

Introduction

There continues to be an explosion of inexpensive yet powerful devices for the home, office, and other mobile/embedded environments (mobile routers/switches for example) that everyone owns and utilizes daily. The market need is finally aligning with recent advances in wired/wireless networking, and advances in pervasive software platforms. Additionally, advances in IP-based sensor networking and more open-standard geo-spatial techniques, offers newer ways to realize the potential.

However, at the same time, wireless networks are being pushed to their limits by highly data intensive applications that are constantly sending/requesting data and computation from centralized servers/clouds. Additionally, companies are weighing the cost of hosting these data intensive services and the privacy concerns of using someone else's cloud.

Finally, today's mobile applications do not live up to their potential in performance or autonomy. Most are still client-server with rigid business intelligence and are too reliant on the network and/or are too centralized to effectively scale. They are not adaptive or self-learning. All of these conditions reveal the need for an advanced pervasive network and software platform to drive the advanced applications needed so badly, according to many of the biggest technology companies pioneering pervasive technology.

Cisco has had a pervasive mindset for some time now. They were ahead of the curve in promoting the need for a unified, pervasive platform to bring additional intelligence to their networks, ubiquitous access to their applications, running on the ever expanding types of devices that we use in our daily lives.

It is the aim of this paper to address at various levels all of Chamber's vision for Pervasive Computing and the technical requirements to implement his vision. The high-level scenarios that are described within the use cases of this paper will require a pervasive software platform and underlying meshed network that is available today.

Defining M2M As Intelligent Device Communities

At VMWorld in San Francisco in September 2007, Cisco CEO John Chambers said the future of IT and business was about a "wave of collaboration across barriers and content"... "Find me, follow me, get access to anything you want," and later he closed by stating that: "You will see a second phase of innovation via virtualization and collaboration - data, voice, video, across any combination of data type, any device, and any network."

The pervasive applications that will enter the market in 2011 will span all of the devices we use today, and impact every aspect of our lives…how we work, learn, communicate, receive medical care, shop, drive, play, watch sports, and protect ourselves, while opening up an entirely new world of business opportunities for the entrepreneur, and established corporations alike. Collaborative applications will also join the hard to collaborate environments of public private-partnerships where dozens to hundreds of entities must work in a secure, but borderless approach to address or capitalize on common community causes from vital resource management of water, energy, and forest to the social inclusion, economic development, and sustainability of large urban centers.

These application will be powered by a next generation software platform that will seamlessly operate in your home, office, auto and mobile and move with you, as you transition from/to the devices used in each setting. It will run on all wireless/mobile networks, allow devices and sensors to discover themselves in an ad-hoc manner, and form dynamic communities that are hosted on virtualized federated servers running on routers/switches in the home, office and enterprise, while seamlessly interoperating amongst themselves along with any enterprise system, public/private clouds or combinations thereof.

The foundation for collaboration will be the ability to form swarming communities on a large scale. These capability-sharing communities will leverage a sophisticated communications infrastructure that allows applications on these "edge" devices, be they business, consumer, military, scientific, human or machine operated, wireless or embedded, to participate in coordinated knowledge sharing, problem solving, and transactional ways, utilizing various network and distributed computing protocols that tap into the layered services from across the ISO layers 2-7. These communities, and the application level services they utilize, will be hosted/offloaded on nearby routers/switches, for quick, efficient application performance and network utilization, rather than in the traditional enterprise/cloud.

Extreme personalization and immersive experiences will characterize the pervasive applications, which turn mobile and embedded devices into wireless learning machines that can detect (and eventually anticipate) information needs/findings that can be either retrieved (locally or from remote device communities) or distributed to the device communities that have expressed interest in such. For example, based on a user's location, time or day, work or play, these devices or device communities will deduce a user's needs and proactively deliver highly individualized content without requiring the user to "Google", or even think about it.

Pervasive Platform Architectural/Software Requirements

Pervasive Applications need to be built upon a Pervasive Borderless Middleware Platform that provides object level mobility, which hides network usage decisions from user applications. Applications written on such a platform can run anywhere, anytime, and exchange any type of data without loosing connectivity with any other peer device, router, switch, system, and/or cloud. In this scenario, anywhere means any device and any network. In other words, applications can maintain their connectivity context while residing on a mobile device and traversing multiple networks, such as Telco, 3G/4G, WiFi and Bluetooth. Similarly, applications can maintain their connectivity, data and execution context while they move from one device to another device using runtime application migration schemes. This "follow-me" application state follows the user as they cross network boundaries, or change devices (home->mobile->auto->office), or the underlying middleware platform decides to utilize a different network for connectivity. The virtualized federated server running on the routers/switches that connect devices and span networks are ideally situated to assist in the migration of application context from device to device.

A next-generation platform, which can abstract wireless networks, operating systems and devices and provide intelligent messaging, communication, and collaboration will enable the next wave of context-aware services spanning applications to advertising to personal advising and recommendations. The following is a list of architectural/software requirements for a pervasive platform (See **Figure 1**) that can handle the demands of a networked world.

Extensive Wireless/Embedded Device Support

A true pervasive application must be able to run peer-to-peer, in some form, on all devices ranging from smartphones, routers/switches, MIDs, UMPCs, Netbooks, VOIP phones, sensors, as well as those found in, or coming soon, to automobiles and remote controlled machines, to name a few. To do so, its software platform must run natively on these same devices. Software agents comprising these applications, also need to be able to run on all of the popular mobile/embedded software stacks, such as Java's Micro Edition, Android, Microsoft's Compact Framework, and OSGI Containers, on a wide range of mobile/embedded operating systems such as iPhone, Blackberry, Windows Mobile, Symbian, BREW, and Embedded Linux versions (Android, LIMO, Maemo, etc.), to name just a few. These intelligent agents will facilitate these pervasive services to function within smartphones, routers/switches, MIDs, UMPCs, VoIP Phones, Telepresence, sensors, automobiles, bus stops, smart meters, and other ICT connected participatory nodes.

Decentralized & Centralized Messaging w/Ad-Hoc Communities

A pervasive platform must enable communication and sharing of application data, between groups of devices/systems without the need for a centralized messaging server. It must support the creation of ad-hoc communities of devices or nodes, as well as the ability to support filtering of application mess*ages across these communities.* Support must exist for devices joining and leaving the network, which will result in changing "internet" addresses. Again, a virtualized federated server running on routers/switches in the home, office, enterprise and auto are natural nodes to efficiently host these device communities and the application level services and data, they wish to share. Integration with a SIP Server is one way to provide dynamic IP support along with voice, data, and chat support over IP. The platform must also support passing messages over standard centralized messaging servers for integration with enterprise and legacy systems. More specifically, there needs to be seamless integration with Microsoft's Message Queue (MSMQ), Java's Message Server (JMS) and Object Management Group's (OMG) Data Description Service (DDS), etc.

Increased Network Scalability, Survivability & Discovery

A next-generation platform must enable filtering and analyzing of data at the source to minimize network traffic, handle unreliable and/or limited network connections, and adjust to hardware failures or CPU load. Therefore, these devices must be able to persist data via a micro relational or objects database. Additionally, the software components or agents running on edge devices need to support multiple wireless protocols (GSM, CDMA, Wi-Fi, UWB, Bluetooth, NFC, RFID, 4G/WiMax/LTE, etc.) and associated networks (Telco, Wide Area, Local, Personal, etc.). Ideally, they will dynamically reconfigure themselves to use a communication protocol that best matches the capabilities of their current network connection and the current node(s) they are in communication with. Also via the pervasive platform, devices must support dynamic discovery of services, services provisioned across the various OSI layers running on nodes in the same network, nodes and trusted layers in a federated network, and trusted nodes in swarming and wolf pack networks. Community hosting, discovery of device services, application data persistence, and software distribution are all capabilities that will be provided by advanced routers/switches located in proximity and federated across the networks to greatly augment network scalability, survivability and performance.

Mobile SOA Architecture & Dynamic Composable Computing

A pervasive platform must also provide an enhanced Service-Oriented Architecture (SOA) that supports services running on mobile and embedded devices. In other words, any device should be able to host and access services. These services need to be accessible via Service Containers that are located on nearby routers/switches, and centralized servers, but also must be accessible in a completely decentralized fashion directly to agents, exposed as services, that are running on edge and wireless devices. The distributed agents must act more as providers of services and facilitators of exchanges and transactions versus a traditional client/server central provisioning approach. The location of intelligent agents/services and the Mobile Web Services they expose must be irrelevant to the client or target device. Finally, all agents/services need to be accessible by a Service Description in adaptive directories, ideally ones with Universal Description, Discovery, and Integration (UDDI) compliance. Finally, these services must be discoverable via the federated routers/switches, which at times will access SIP/IMS registries and other network-based discovery techniques for advanced abilities to compose and provision services across the layers.

Configurable, Adaptable Security Framework

In a ubiquitously networked world, it will often be necessary to maintain data on edge devices. The security concerns facing enterprises today will need to incorporate solutions that extend to a collaborative environment. Pervasive platforms must provide a high level of security to ensure privacy and protection from rogue/viral clients and software agents. This will involve security agents and agent managers that provide capabilities above and beyond the current encryption, authentication, and authorization that are currently employed in today's centralized client server applications.

As with every capability within the pervasive platform, the security capability needs to be configurable and pluggable, to allow for adaptable and custom security features specific to the data and/or services being hosted on any particular node. For example, encryption, authentication, and authorization around peer-to-peer and peer-to-group application/event exchanges should all have pluggable security capabilities that tap into the various security services from networks, to clouds, to applications, and so

To achieve Chamber's vision of **"any device to any content wherever it is in the world over any combination of networks"**, pervasive apps need to support most, of these components.

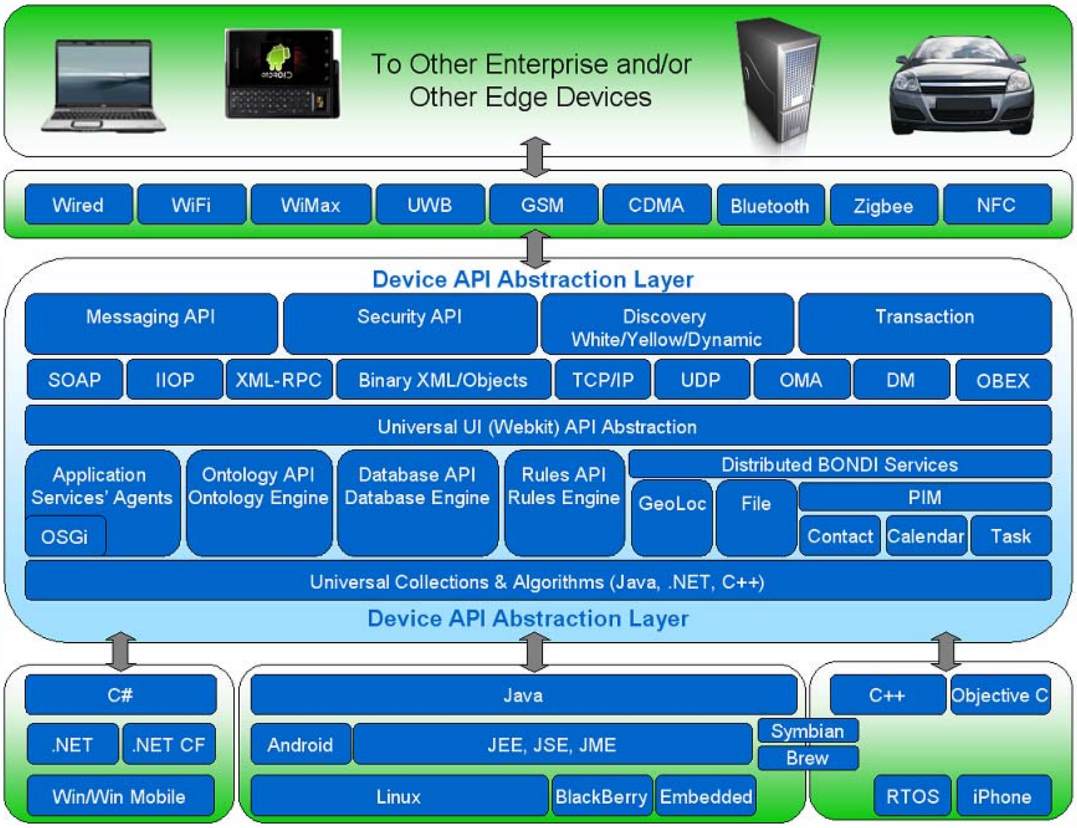


Figure 1: Device Architecture

forth. Security Agents, Agent Managers and accompanying security rule sets, will be hosted on the router/switch-based virtualized federated servers. Optionally the router/switch will be able to deploy such agents, managers and rules to the edge devices for autonomous security management.

Universal Platform/Services- .NET/Java/C++/JS from Clouds to Sensors

These sophisticated applications cannot be limited to a single development environment and programming language. Furthermore, the same API should be provided to .NET, Java, C/C++ and JavaScript developers. The platform should support a common set of collections and algorithms across these languages as well. This would greatly increase programmer productivity and allow developers from all camps to easily work together and share software. The platform must seamlessly integrate with .NET, JEE and legacy (MVS, CORBA, etc.) enterprise systems and services, and any combination thereof, in either a traditional Web Services architecture, or in a high performance manner using binary protocols. Pervasive applications may need to communicate with more than one enterprise/organization or governmental entity. Transactional coordination of application requests to multiple enterprises and clouds will be the responsibility of the virtualized federated servers running on routers/switches.

Additionally, with the advent of Software-As-A-Service (SAAS) and Infrastructure-As-A-Service (IAAS) based cloud computing, there will be an evolving need for inter-cloud interoperability. This holds especially true since companies, organizations and governments are adopting cloud computing at every level. Protocol standards are being debated here, and likely will never be universally agreed upon. This all furthers leads to the need for pluggable protocol architecture since different nodes, systems, clouds and devices will need to communicate using different protocols, at different times, for different reasons. Again, the server running on federated routers/switches is an ideal node to inform clouds of the protocols needed for inter-communication, as well as intelligently reformat protocols to further facilitate cloud-to-cloud interoperability.

The platform needs to extend from the afore-mentioned enterprise, desktop and mobile/embedded environments down to the very nodes, sensors, and devices. This paves the way of providing Distributed Knowledge Networks (DKN) that extend to and integrates with Intelligent Sensor Networks (ISN).

The ISN will provide sensor instrumentation architecture with rules-based software agents that will provide self-monitoring, self-healing, non-intrusive data transfer methods. The architecture will also describe data routing, multi level security and delivery rules for node collaboration on networks. These robust ISNs will have the capability to reconfigure; self-heal/organize, and adjust to changing data needs and network node availability dynamically as an event evolves. They will do so by leveraging peer-to-peer and peer-to-group communication with like sensors nodes as well as more robust mobile and embedded devices. Logic to filter and analyze data, and distribution of more refined information the data, will occur closest to data's the point of origin where/whenever sufficient processing power and energy sources allow.

Location & PIM Peer-to-Peer/Group Services

To enable location-aware, community-based, collaborative applications, the pervasive platform should provide location and PIM services that allows determination of any node's location from any other node, as well as sharing of such information as contacts, calendaring, tasks and files (audio, video, photo, etc.). These services will form the building blocks of many ad-hoc, community-based applications. These APIs should be compliant with standards, such as BONDI, and be consistent across all platforms, languages and devices, and must be accessible by both peer-to-peer based messaging, peer-to-group messaging across dynamic communities hosted on router/switch-based federated servers, and of course peer-to-enterprise/cloud for integration with enterprise systems, SAAS and IIAS clouds.

Universal UI API

A pervasive platform ideally will also provide a Universal UI API, to compliment its Universal API's for discovering, accessing and hosting services and data across all devices. Considered nearly an impossible task, technology has evolved to make this feasible in a standards-compliant, truly ubiquitous manner. More specifically, WebKit (based on HTML 5 and JavaScript 1.5) is becoming very prevalent on desktops and mobile devices. Android/Chrome, Apple/iPhone/Safari, Symbian/QT and RIM all have WebKit support within their SDKs via their own APIs. Therefore, WebKit, Microsoft's Silverlight and Adobe Flash seem to be poised to be the dominant "web engines" across all devices. A Universal UI Interface that can communicate with a web engine would allow developers to have their application process layer communicate with a presentation layer, all utilizing a single set of APIs.

Transactional on Edge Devices & Ad-Hoc Communities

A pervasive platform must extend transactions from the enterprise to edge devices, allowing for distributed, but coordinated tasks and information sharing and collaborative communications among peers, peer groups, enterprise, cloud, and federated clouds. Support must be provided to allow for intelligent agents/services running on the edge to participate in guaranteed service, message, and communication delivery via federated routers/switches that provide such pub-sub messaging and transactional services directly and, when necessary, communicate to enterprise JMS/MSMQ servers, or with XA-compliant enterprise transaction managers such as those provided in .NET's Microsoft Transaction Service (MTS), Java's Transaction Service (JTS), OMG's Object Transaction Service (OTS) or ATMI-compliant TM's such as Tuxedo.

Embedded & Enterprise Database Integration & Synchronization

This advanced pervasive platform must provide a simple way to access databases, regardless of the type of database-whether it is a relational, object, XML or a multi-user enterprise database or single-user embedded. Developers need to be shielded from the intricacies that exist with these various flavors and have support for data synchronization between a mobile/embedded device, the communities of devices it belongs to, and enterprise systems such as Software and Infrastructure-As-A-Service (SAAS, IAAS) Clouds. By providing this level of abstraction, pervasive applications built using this platform should be able to leverage the high-performance, highly distributed databases being developed for advanced, high-speed full-text, binary as well as multimedia searches that are making their way into non-traditional environments such as smartphones and routers/switches. The most efficient way to provide multi-device data sharing/synchronization is through federated servers running on nearby routers/switches, that communicate with centralized servers and clouds.

Support for Complex Event Processing (CEP) on the Edge of the Network

A pervasive platform with the capabilities described above has the ability to filter and analyze data on any node and distribute the resulting universal business/data to any other node, or interested groups of nodes regardless of their location and software platform.

The data will often originate from a wide range of sources often from sensory/mobile/embedded devices. The filtering, analyzing and distribution of information/events will first occur as close to the sensory/mobile/embedded device as possible (ideally on it). They will then be further processed, by similar services running on more robust routers/switches, and results propagated to the communities of devices the routers/switches are hosting. Such is the basis of the aforementioned ISN.

Additionally, such a pervasive platform can support dynamic groups that represent connected and/or hierarchical analysis/decision support/collaboration groups. Each groups and group level analyzes micro events in determining relevant, increasingly coarsely grained, macro events leading to additional data/event filtering, analyzing, collaboration, response and also for determining the routing of that information to enterprise systems/clouds (governments, corporations, research institutions, trading floors, health organizations, etc.). This results in the transformation of sensory data to knowledge (DKN) and ultimately to situational awareness and actionable knowledge in real-time or near real-time (CEP).

The data traversing this ISN/DKN/CEP needs to be able to navigate firewalls, support (NAT), and be transportable to communities of disparate devices applications, systems and clouds that have expressed interest in receiving such data. This is greatly facilitated by many horizontal and vertical application level services being hosted on routers/switches that are integral nodes comprising the NAT topology.

Every aspect of the platform's flexibility and support for heterogeneous nodes, protocols, networks, messaging and discovery capabilities is fully leveraged in such a scenario.

Pervasive Scenarios & the Router/Switch-Based Federated Virtualized Server

In each of the scenarios described below, many of the horizontal and vertical application level services are hosted on the routers/switches located in the home auto, and SMB, enterprise, cloud. They include the following federated services:

1) Horizontal Application Services including:
   - Security and Identity (encryption, authentication/ authorization)
   - Discovery (white/yellow pages)
   - Persistence and Data caching
   - Data indexing and searching
   - Transactions
   - Location information sharing
   - Community hosting
   - Community-to-Community Application Messaging
   - Auditing and logging
   - Software/rule-set distribution
   - Application Service maintenance
2) Proxying service requests to centralized servers/clouds/services when necessary
3) Dynamic Application Computation offload
4) Dynamic Application Data/Traffic/Transport/Media Optimization
5) Application Services that are specific to the scenarios outlined below

Pervasive Intelligent M2M Sensor Network

Recently, there has been conscious and concerted global effort by scientists, citizens, governments world bodies, public sector agencies, NGOs and the private sector to monitor, track, collect, filter/mine, distribute data, analyze, predict and take action when managing disasters, climate/environmental change, world resources, disease, etc. Given the multidimensional complexity, achieving distributed collaborative and unified coordination is a Herculean task. The optimal approach is a pervasive intelligent sensor network (see **Figure 2**). Such an ISN enables hierarchical and federated virtual information exchanges with decision support systems and data visualization front-ends, ensuring deeper fidelity and more collective transparency by various scientific, socio-economic, political, business and/or governance models.
The base layer of such a pervasive connected earth fabric is an intelligent sensory swarm. Unfortunately, the datasets from such sensors tend to be very large, poorly formatted and stored, widely distributed and difficult to access. Finally, such data is of less use unless it is tied to decision support systems and made available to respective stakeholders in a useful visual manner. This is where a pervasive platform's intelligent data synthesis and distribution at the very edge of the network, is paramount.

In intelligent sensory swarm, a sensor could be a satellite/airborne remote sensor, specialized ground sensor or potentially mobile devices or vehicles (cars, fleets, etc.). Each of these sensor types can create dynamically assembled hierarchical clusters. Sensors at the lowest level cluster will gather desired sensory data in a pre-defined or ad hoc way, which then leads to taking the data and applying micro-filters that create and index the data. The indexed data triggers events and distributes the information or meta-tags of the information to the gateway/mobile router/switch in the higher-level cluster, either responding automatically or waiting to respond upon the right triggers. The router/switch can distribute information to its federated peer routers/switches and eventually to the distributed data centers and network clouds of respective jurisdictions.

Next layer of the pervasive connected earth fabric is the federated virtual information exchange platform. This is an abstraction layer analogous to web collaboration platform Google Wave, however more pervasive, distributed, dynamic and peer-to-peer/peer-to-group/group-to-group in nature. It encompasses federated routers/switches which are connected to dynamically assembled federated distributed data center and network clouds, where clouds could be public or private data center clouds, network clouds, or loosely coupled mobile devices and vehicles. Moreover, these clouds may belong to diverse range of world bodies, governmental entities, NGOs, private sectors, and/or individuals.

Using a Pervasive Platform that extends from sensors to mobile/embedded devices, routers/switches, switches and finally servers, information can stay at its source or close to the source, and then is accessible through structured and unstructured queries based on events or actions, allowing for the coalesced responses back to the highest level in the pervasive connected fabric. Information obtained in this mechanism is near real-time, thus enabling accurate decisions/inferences by the respective stakeholders.

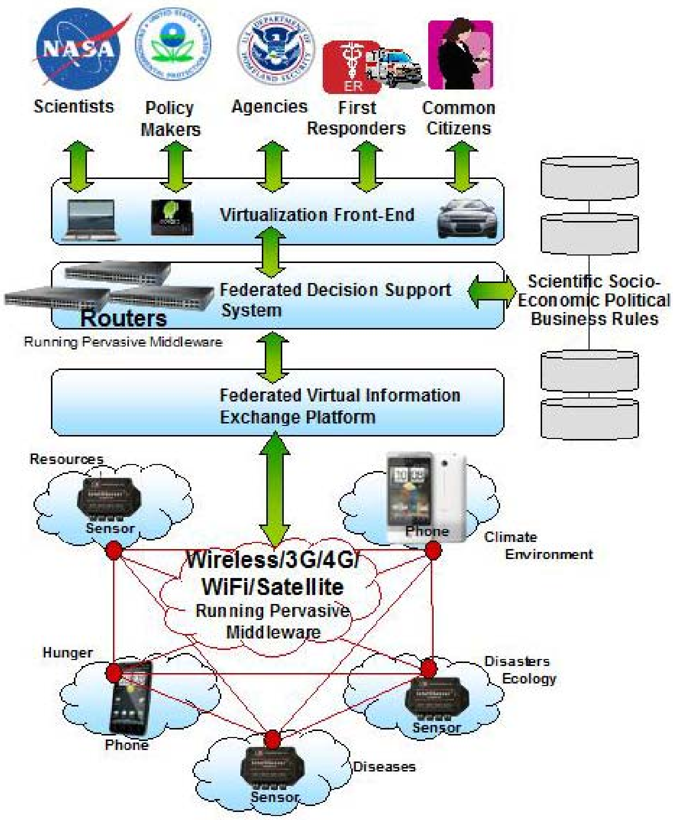


Figure 2: Pervasive Connected Earth Fabric

The decision support system, which presides over the federated virtual information exchange platform, provides tools that are driven by the scientific-socio-economic-political business rules. These tools allow the dynamic creation of filter rules that can be distributed from the highest level of the pervasive connected earth fabric to federated routers/switches and on to the lowest level sensors, so that sensory data can be transformed into situational aware, actionable information. Similarly, tools allow the dynamic creation of query rules in order to extract coarsely grained, actionable information originated from federated clouds, which originated from hierarchy of sensor clusters. Finally, tools such as analytics and prediction tools help stakeholders to take positive and measurable action on the information.

Federated Router/Switch-based Application Services:
Indexed and Searchable Location, Sensor, Weather, Contact, Roles, Skills, Calendar, Task, Chat Data and Multimedia Files

Pervasive Federated Enterprise Architecture For Fortune 50's To SMBs

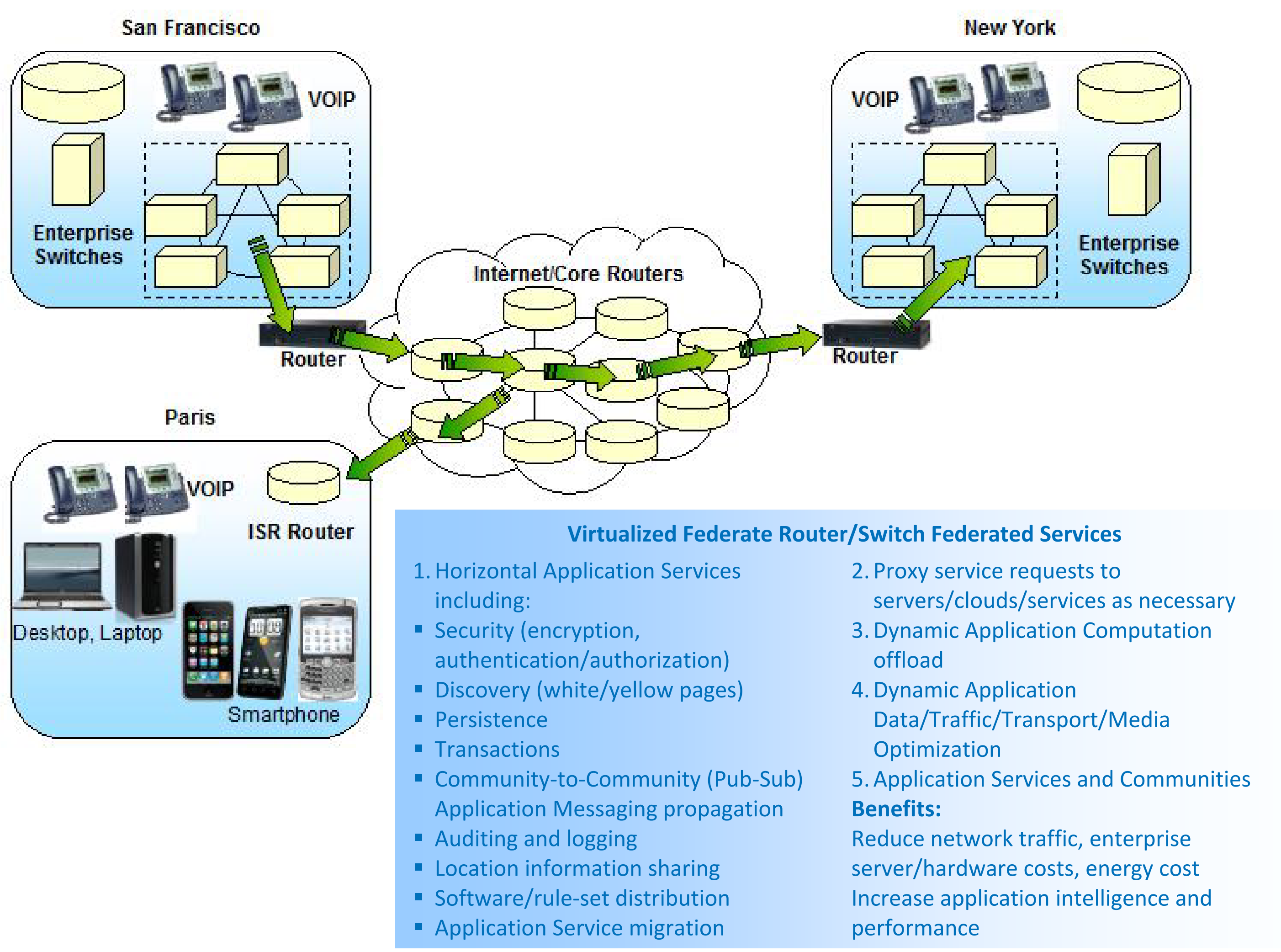
As stated previously, a pervasive software platform allows for services to be hosted on the devices we use today resulting in peer-2-peer and peer-2-group application-level messaging across heterogeneous device sets. These groups are virtual communities that can be statically or dynamically formed and managed. Additionally, these communities can contain any collection of devices including: servers, routers/switches, switches, desktops/laptops, tablets, MIDs, UMPCs, netbooks, smartphones, media storage devices, VOIP phones, and sensors. Importantly, these communities can be chained together and nested to form sophisticated application-level messaging topologies.

For example, some global enterprises have a main corporate data center, and field offices spread across a region, country or globally. In this case, the Branch/Field Offices can be peer-communities that are nested within the community of the enterprise. Additionally the Branch/Field Offices can contain sub-communities for the various groups that operate within that particular office. Additionally, the heterogeneous devices can participate in more than one community. The router/switch is a natural node to host these communities and the horizontal services described above and application services described below.

In larger global enterprises consisting of several large data centers or for companies that host a data center with high volume web traffic, there is often the presence of "n" switches behind the "public" facing router/switch (see **Figure 3**).

Switches are also natural nodes to act as virtualized federated servers hosting the same horizontal and vertical services. In this case the public facing router/switch will be part of a community within a datacenter and can share the load of handling horizontal and application level services (security, data access, transactions, logging/auditing. etc). Additionally the communities of routers/switches within each datacenter can be nested within a larger enterprise community that can coordinate transactions, data synchronization and data replication that can span across the various data centers.

In many cases this will greatly reduce the need for much of the hardware associated with running application servers, resulting in decreased capital and energy costs, increased performance scalability, and real-time data sharing/synchronization across enterprise data centers, central offices and field/branch offices.



Federated Router/Switch-based Application Services: Location, Contact, Calendar, Task, CRM, ERP and Business Data, Chat, Multimedia File Sharing, Video Conferencing and Whiteboard Capabilities

Conclusion

As echoed by the leadership at Cisco, there is the need for a federated, efficient, high-performance, network-friendly, pervasive platform that provides interoperability, data sharing, mobile collaboration, and seamless "follow-me" content and services across most public and private industries. There is also an equal need to accomplish such while utilizing networks more efficiently, reducing hardware and energy.

Routers/switches in the enterprise, SMB, home, auto and public locations are ideally positioned to become virtualized federated servers that provide application services to the nodes they are already providing networking connectivity, and routing data packets for today. These intelligent routers/switches will reduce network traffic, enterprise server costs, energy costs and will increase application intelligence and performance on all devices. They will play a vital role in the green Intelligent Network of Things, next-generation federated data centers, and the advanced mobile and enterprise applications, and services running on them. Such a pervasive platform is much closer to reality than many may realize and indeed will change the way we work, live, play, drive and learn. ▪

For more information on the ideas discussed within this paper, or to view a prototype of the technology described, contact the authors or Cisco at 408.526.4000 or Recursion Software at 800.727.8674 or marketing@recursionsw.com.