Pervasive Virtual Information Exchange Platform
A Federated Architecture from Sensory Swarms to Mobile Devices to the Cloud

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Abstract—This paper will discuss the pervasive software and network architecture required to form the foundation of Distributed Knowledge Networks (DKNs) and Intelligent Sensor Networks (ISNs) that span home and office, mobile and embedded devices, sensors, autos, and the cloud.

The paper will highlight how such foundations accelerate the development and adoption of immersive geo-spatial decision spaces where mashed up isolated data sets from public, private, and/or non-profit sources are combined with human networking and social networking capabilities. The Emerging combined effects resulting from these combinations will produce higher situational awareness, context aware option analysis, and interweaved collaborative environments harnessing the swarming nature of humans, machines, and sensors of distributed participatory networks.

The paper presents the architecture's use of software agents integrated with rules engines to form an intelligent, ubiquitous collaborative communications platform that allows for ad-hoc, dynamic peer-to-peer, peer-to-community, peer-to-cloud/enterprise application, and peer-to-intercloud exchanges. All of which facilitates the provisioning a multi-layer and open-standards based communication, messaging, and trusted fabric that spans a wide range of devices from servers to clients to mobile devices to sensors.

The requirements of such a pervasive software platform will be presented as well as the architecture needed to support such. It also discusses how this architecture will allow applications and application state to move peer-to-peer and peer-to-community so that users, and groups there of, can seamlessly move from one device to another (home<->mobile<->auto<->work<->cloud) without interruption or loss of data. We further go on to describe the "follow me" state capabilities, where the content and state follow people, products, processes, and nodes within the trusted groups and communities. Capabilities are ideally suited for confederated collectives and communities that participate more in an ecological way vs. traditional enterprise approaches.

Finally, various scenarios that will greatly benefit from such a platform will be covered that span location-aware, pervasive collaboration, connected home, urban/regional wide platforms, emergency/first responder, and especially highly complex planet-wide intelligent sensor network and earth resources management systems.

Keywords--pervasive software, pervasive fabric, pervasive architecture, pervasive applications, pervasive middleware, mobile, wireless computing systems, ad-hoc networks

I. INTRODUCTION

Pervasive software has been discussed in academia for some time now, but has yet to be realized. What does it mean to the average professional, consumer, military person, or scientist… people who are not in the software world? How will it change our lives? How does it help facilitate collaboration? How does it improve decision-making? Is it technology for the sake of technology? How will it be realized? What will "pervasive software" look like architecturally? What will its capabilities be? What pervasive applications will result? When will it, and the applications it enables, get here? In what ways does it help realize the requirements of the business architecture?

It is the aim of this paper to address at various levels all of the above aspects of Pervasive Computing. The good news is that it is the strong feeling of these authors that the foundation for pervasive services is here…and we will begin to see the applications that will be built on it change all of our lives as they are launched within the next year. It is an extremely exciting time where all the necessary ingredients are coming together. There continues to be an explosion of inexpensive yet powerful devices for the home, office, and other mobile/embedded environments (mobile routers for example) that everyone now own and utilize daily. This is aligning with advances in wired/wireless networking, and advances in pervasive software platforms. Advances in IP-based sensor networking and more open-standard geo-spatial techniques, offers newer ways to realize the potential.

II. Pervasive Is Now

Cisco and Microsoft, arguably the biggest names in networks and software/operating systems, have had a pervasive mindset for some time now. They are correct 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.

At VMWorld in San Francisco back in September 2007, Cisco CEO John Chambers said the future of IT and business was about a "wave of collaboration across barriers and content. There will be a wave of productivity that will change how we work and the very nature of work itself." "It's about convergence of voice, video and data all stored in places you have difficulty getting to, such as in the home on small devices." "All this will be enabled by unified communications," he said.

In his speech, Chambers coined it as "Find me, follow me, get access to anything you want," and later 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." [1]

Back in September 2005, Chambers gave a presentation to MIT entitled "The Power of the Network to Change the Way We Work, Live, Play, and Learn." [2]

More recently Info World Q&A with Chambers March 2010, Chambers re-enforced these concepts "It's not the data center or the user device. It's any device to any content wherever it is in the world over any combination of networks wired or wireless to the home, to an Apple device, to a Microsoft device, to an IBM device, HP. Doesn't matter to us." "We think the ultimate intersection will be a confederation, where it is completely transparent to the end-user, the CIO, and up." [3]

Not surprisingly and very much in this vein, Cisco is involved with three initiatives, Planetary Skin, Connected Urban Development, and Smart+Connected Communities, which are extremely exciting and ambitious global incarnations of Chamber's vision. They are collaborative efforts involving cities and governments around the world, as well as with NASA (Planetary Skin) [4] and MIT (Connected Urban Development) [5]. The high-level scenarios of which that are described below will require a pervasive software platform and underlying meshed network that is at the heart of the content of this paper.

Bill Gates and Steve Ballmer have each echoed similar sentiments. Gates expressed in this final keynote at CES in January 2008, "The second digital decade will be more focused on connecting people. …[Applications] will run not only on the PC, they'll run up in the Internet, or in the cloud, as we say, on the phone, in the car, in the TV. The applications will use the best of rich platforms and those Internet services." [6]

And Ballmer noted at CTIA WIRELESS & IT in October 2007, "We need to bring together four powerful computing phenomena that exist today: The desktop PC, enterprise computing, mobile services running in the cloud and phone devices… The other thing which I think our industry needs, so that all of our innovations can add up where the whole is bigger than the sum of the parts, is really a rich platform that supports work style and lifestyle innovation on the phone." [7]

The authors of this paper are in complete agreement here. Pervasive services and applications will span all the devices we use today, and indeed many that we don't even realize we are "using", namely mobile routers, embedded devices and sensors in our home, office, auto, and in stores, malls, on road, and ultimately on and even in our bodies. Will many of these devices be running some flavor of Windows as Ballmer suggests? Certainly. But a tremendous amount of them will not be.

III. Pervasive is Intelligent Device Communities

Pervasive software will be the foundation of what drives a new world of highly advanced, provisioned services that will start entering the market in 2010. The applications and decision spaces taking advantage of these services 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, play, watch sports, protect ourselves, manage global risk, and protect countries' interest, while opening up an entirely new world of business opportunities for the entrepreneur, and established corporations alike. Pervasive software in the future will also address the hard to collaborate environments of public private-partnerships where dozens to hundreds of entities must work in a 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 capabilities will be powered by a next generation 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 while seamlessly interoperating amongst themselves along with any enterprise system, public/private clouds or combinations thereof.

This is the foundation of peer-based application groups or communities. But to realize the true power of these intelligent swarming communities, pervasive services must be realized 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.

Extreme personalization and immersive experiences will characterize the pervasive applications and spaces, 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. These "killer" applications are not light years away but are in active prototype development.

IV. Pervasive is Borderless Networks And Applications

Pervasive Applications will 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/system/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 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. This pervasive technology is the foundation that will enable next-generation "Collaboration in Motion".

V. Pervasive Leaves No one (Developer, Device, Sensor, or User) Behind

Now the obvious question remains, what options do the software architects and engineers have to build the pervasive applications that run on all or various subsets of the devices previously mentioned? What platform will convincingly abstract networks and protocols and device APIs to begin to address the "write once, run everywhere" conundrum that Java alone failed to deliver? Advances in next-generation pervasive middleware are addressing many of these problems. Such tools will be an integral part of achieving complete interoperability.

VI. Pervasive Platform Architectural/Software Requirements

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.

A. Extensive Wireless/Embedded Device Support

A true pervasive, peer-to-peer application must be able to run, in some form, on all devices ranging from smartphones, routers, MIDs, UMPCs, Netbooks, VOIP phones, sensors, and 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 in 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. All of which will facilitate these pervasive services to function within smartphones, routers, MIDs, UMPCs, VoIP Phones, Telepresence, sensors, automobiles, bus stops, smart meters, and other ICT connected participatory nodes.

B. Decentralized and Centralized Messaging w/Ad-Hoc Communities

A pervasive platform must enable communication and sharing of application data, between groups of

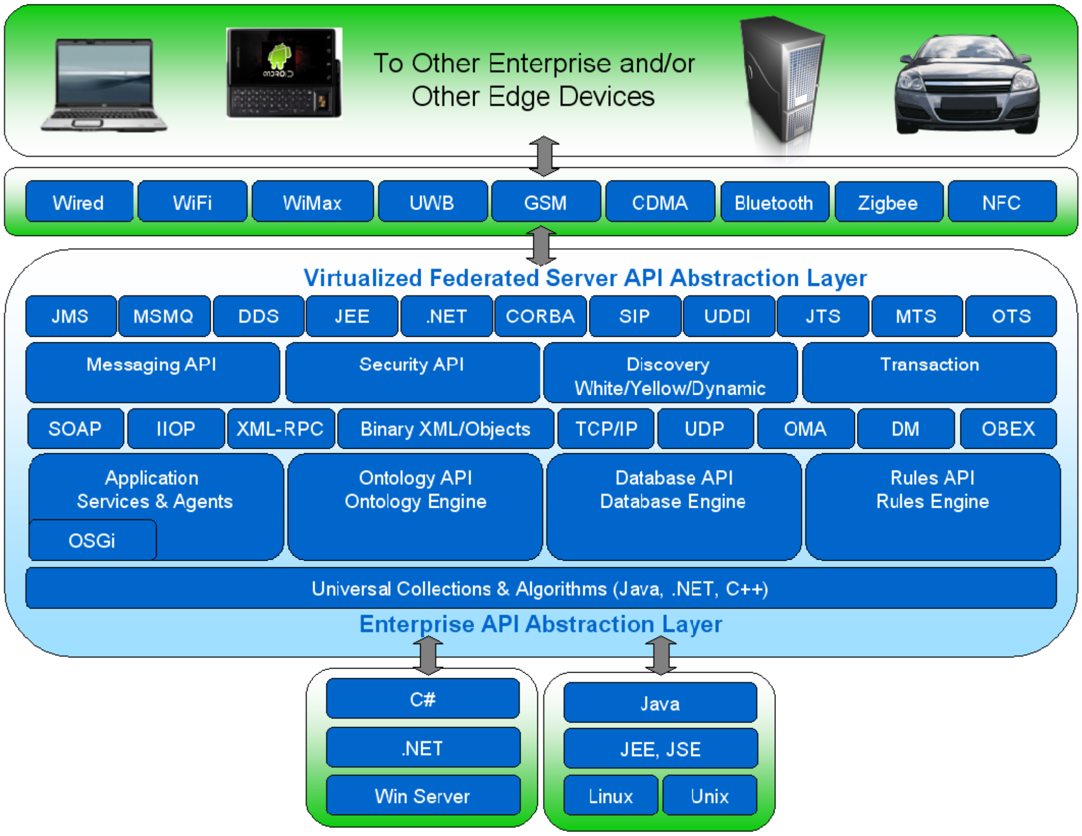

Figure 1: Pervasive Software Platform Architecture

devices/systems without the need of 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 messages across these communities. Support must exist for devices joining and leaving the network, which will result in changing "internet" addresses. 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.

C. Increased Network Scalability, Survivability and Discovery

A next-generation platform must enable filtering and analyzing of data processing 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.

D. Mobile SOA Architecture and 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 centralized Web Service Container, but also must be accessible in a 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 over SIP/IMS registries as well, along with network based discovery techniques for advanced abilities to compose and provision services across the layers.

Along these lines, the platform should also support what is called Dynamic Composable Computing (DCC), which allows for applications on devices to leverage the applications, services and thus even hardware capabilities of another device. [8] For example, a smartphone running your mobile application can sense it is now located near another device of yours (or vice-versa) that has a larger display, and/or more processing power, such as your desktop, laptop or the computer in your car. A DCC or Mobile peer-based enhanced SOA capability allows for the smartphone to transfer the application's state to the other device (and vice-versa) to leverage its screen size and/or processing and/or storage, or simply because that is the device you are transitioning to.

E. 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 date 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 forth.

F. 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.

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.

The platform needs to extend from the fore-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 where/whenever sufficient processing power and energy sources allow.

G. Location and PIM Peer-to-Peer and Peer-to-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 and of course peer-to-enterprise/cloud for integration with enterprise systems, SAAS and IIAS clouds.

H. 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 all have WebKit support within their corresponding platform's SDK via their own APIs. RIM will be following suit this summer. So WebKit and Microsoft's Silverlight seem to be poised to be the two dominant "web engines" across all devices. A Universal UI Interface that can communicate with WebKit and Silverlight, would allow developers to have their application process layer communicate with a JS/HTML presentation layer, all utilizing a single set of APIs.

I. Transactional on Edge Devices and 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 either via an enterprise pub-sub JMS/MSMQ-like capability described above, or with XA-compliant enterprise transaction managers such as those provided in .NET's Microsoft Transaction Service (MTS), Java's Transaction Service (JTS), and OMG's Object Transaction Service (OTS).

J. Embedded and Enterprise Database Integration and Synchronization

This advanced 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 searches that are making their way into non-traditional environments such as smartphones and routers.

K. Artificially Intelligent, Cognitive Edge Processing

Finally, a next-generation application will need to utilize intelligent software agents/services that can gather data, respond quickly based on this data as it changes, produce and distribute knowledge, and even initiate other agent/service activities on another device or group thereof. The underlying rules engine must be easy to use, provide very high performance against potentially large rule sets, and must be available in multiple languages. These agents should also be able to understand different ontologies as a powerful abstraction to the modeling of knowledge about different domains.

L. Resulting Support for Complex Event Processing (CEP)

A pervasive platform with the capabilities described above has the ability to filter and analyze data on any node and distribute 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). 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 level of groups 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.

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

VII. Pervasive Application Scenarios

A. Pervasive Connected Earth

For the past decade, the debate regarding the fate of planet earth has greatly intensified. Rapid industrialization and the high-tech revolution have touched the life of every human being. However, out of this rapid expansion arises the need to closely manage and monitor the planet earth's vital resources, its life and its habitat. From scientists and politicians, to average citizens, climate uncertainty and scarcity of vital resources such as water, food, forest, and energy have become household talk. In addition, accelerating population growth is becoming unsustainable and unmanageable by the current approaches to resource management, let alone after any potential climate-related affects, whether natural or anthropogenic, on those resources. Not to mention hunger affects close to a billion people worldwide [12]. Thousands of plant and animal types are endangered and close to extinction. Finally, with today's modern transportation system the world is becoming increasingly interconnected, allowing diseases to spread rapidly causing global pandemics, or increasing the odds of higher loss of life rates and enormous economic impact from natural disasters due to clustering of humans in major centers. The 2010 earthquake in Haiti is one recent example.

Scientists, citizens and governments alike have come to a realization that something needs to be done for to deal with uncertainty, risk, and management of our Planet Earth. Recently, there has been conscious and concerted global effort by world bodies, public sector agencies, NGOs and the private sector to monitor, track, collect, filter/mine, distribute, analyze trend, predict and take appropriate positive and timely action to manage disasters, climate/environmental change, world resources, hunger, diseases, etc. Given the multidimensional complexity, achieving distributed collaborative and unified coordination is a herculean task. One such approach to the above is a pervasive connected earth fabric (see **Figure 2**). Such a fabric should enable 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. For example, Federation of Information Earth Science partners, including NASA [13], ESA, INPE, NOAA, USGS, and SIDC, use satellite based remote sensors in order to monitor and track environment and climate change, as well as ground-based sensors, which have huge potential to provide valuable scientific data. However, the dataset 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.

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 could create dynamically assembled peer-to-peer 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 node in the higher level cluster, either responding automatically or waiting to respond upon the right triggers. Eventually information or meta-information must be shared with the distributed data center 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 [14], however more pervasive, distributed, dynamic and peer-to-peer/peer-to-group/group-to-group in nature. It encompasses 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.

Information exchange among these hierarchical sensor clusters and eventually to a distributed data center and network cloud node, could be achieved using a pervasive computing model comprised of any of the following: xml data model, peer-to-peer/peer-to-group publisher/subscriber model, binary XML or XMPP-RPC like communication and computing model, federation discovery, distributed indexing with query response model. XML based distributed query-response has been discussed in a framework called XTreetNet by researchers at AT&T labs [15]. In this model, 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.

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 could trickle down from the highest level of the pervasive connected earth fabric 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**.**

The top layer is the visualization presentation layer, also considered the window to the pervasive connected earth fabric. Information in this sensory world means different things to different constituents including scientists, policy makers, enforcement agencies, first responders and common citizens, respectively. However, if access to policy driven visualization is available, then each constituent could potentially customize their own visual representation from finely grained to coarsely grained detail. For example, if climate change parameters such as CO2 were tracked and visualized using something like NASA's three-dimensional visualization tool on a global and near real-time, this application could enable G-8/G-20 leaders to do on-demand carbon trading during G-8/G-20 summits. In a second example, if global hunger is geo-location tracked [16] and visualized on an earth map (Google, MSN, OpenStreetmap, etc.), this would enable various world agencies to supply food to the people in need. A third example in which resources such as inland water supplies and their continued availability and quality were monitored could help scientists study water pollution, water scarcity and their impact. As a final example, a worldwide-focused organization such as CDC [17] can do real-time tracking using visualization heat map of diseases and predict its spread, can quarantine and prevent a pandemic.

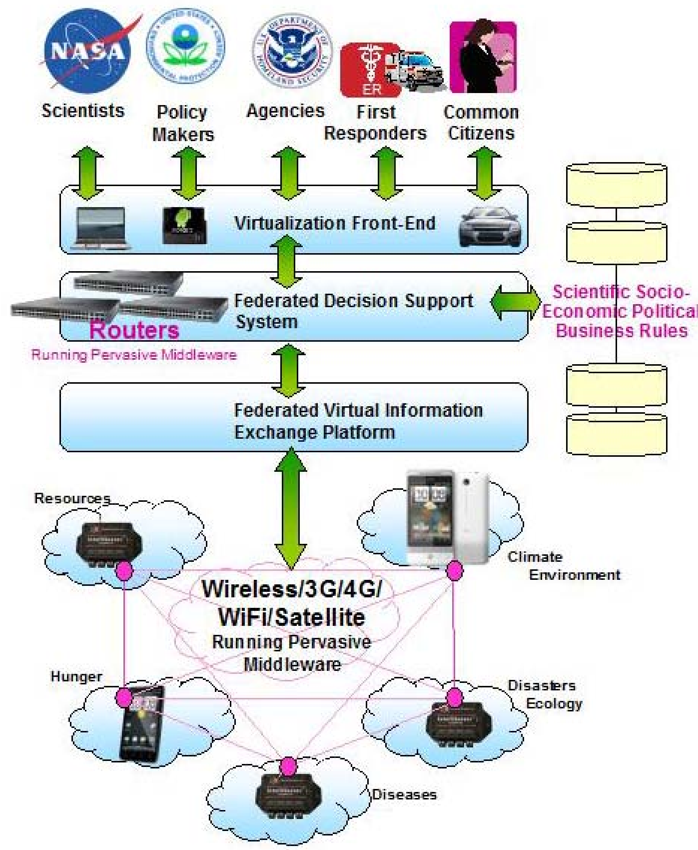

Figure 2: Pervasive Connected Earth Fabric

B. Urban Wide Connected Platforms

We live in a world where 75%-80% of the world's population reside in urban centers. The majority of economic growth and social innovation will also take place within, around, and in between these urban epicenters of activity. With the large potential for improving work/life quality for citizens also comes the burden of managing the balance of resources and sustainability, let alone safety and security, education, and health.

In the future, cities and urban centers require a pervasive technology approach that brings citizens, city managers, and participants within cities together via a federated information network with access to real-time data and expert participants. Such a capability today is not possible due to the complexity of disparate systems and sources of data across cities, let alone the quality and comparability of the data. Further complicating this challenge is the involvement and sense of a common cause amongst citizens and participants within the urban centers.

Personal mobile users are interested in interacting with their environment in ways that help them make decisions about work/life aspects, from energy monitoring within the home to energy efficiency of business to sustainable transportation options, to understanding how the urban policy and programs can benefit them as a citizens.

Mobile devices must be able to sense location, aggregate types of related data to that location, and then provision related service offerings, including but not limited to location-based mobile retail scenarios made popular by movies. By combining augmented reality features with a pervasive computing platform, citizens will be able to aggregate their consumption data (energy, water, utilization, green rewards, economic rewards, etc.) into an environmental or economic footprint segmented by location (building, street) or service (transportation option).

This capability can extend beyond individual citizens to include public and private entities, the sum of which creates the sensory ecosystem of an entire city.

The interconnections and pervasive computing scenarios we propose in this paper offer pioneering approaches to overcoming persistent challenges faced by members of smart+connected urban communities. In order for this vision to be realized, most nodes on the network will need to be active contributors versus static, individual actors computing in isolation via traditional centralized approaches.

C. Pervasive Collaboration In Motion

Real-time location, collaboration and content (contacts, calendars, tasks and files, including audio, video or secure documents, etc.) distribution with your family, friends, and colleagues (and various combinations/subsets thereof) is no small feat when you have no control over what devices the desired participants own, or may be utilizing at a given moment. This is due in part to the underlying fragmentation and portability issues of so many mobile/embedded devices. This scenario goes far beyond sync technologies, which are often wired and confined to a single mobile personal device and your desktop, etc., and is beyond typical cloud collaboration platforms that are static and lack data privacy.

A pervasive software platform enables access and real-time sharing of the above information seamlessly across the various devices that professionals and consumers use, keeping all devices up to date. The pervasive capability can extend PIM data or content to other devices besides smartphones, including cars, home/office mobile routers, VOIP phones, home media hubs, set-top boxes, and other wireless devices.

This scenario (see **Figure 3**) applies to various use cases, from consumer, to corporate, and even battlefield settings. In a deployed field and technician

Figure 3: Pervasive Collaboration

situations, accessing location and presence of company personnel quickly and requesting assistance is key in many situations. A pervasive platform enables ubiquitous, location-aware, CRM services where users can share contacts, information, and request assistance throughout an entire ad-hoc community engaged.

A technician adds the contact, and scheduled follow-up work task for a supporting the incident or investigation. This information is then distributed throughout a designated community. Additional information, such as severity level of incident and other details, are distributed throughout the community, including a SaaS CRM cloud. This is all done while members are moving from one device to another, such as from conference-to-car-to-office etc.

D. Pervasive Connected Home

Today, most of the home devices have some sort of processing power, storage and are either connected via wired or wireless internet. The consumer industry is moving towards truly pervasive connected home (see **Figure 4**). This allows home users/devices to discover, access, monitor, control, share and collaborate across a variety of wired and wireless networks, such as Powerline, Cat3, Ethernet, Wi-Fi, Ethernet, Zigbee, Bluetooth, Infrared, RFID, Cellular and broadband. The trend is to use innovative technologies to make a home that is smart, connected, safe, secure, energy efficient, and to experience true work mobility, especially across multiple public and private federated communities.

A first scenario is to offer consumer devices can easily discover, share and stream digital content (including DVR recordings, music, photos and videos) between consumer electronics (CE) devices, mobile handsets, set-top boxes (STBs) and personal computers (PCs) anywhere throughout their homes.

A second scenario is to enable homes to participate in Smart Grid technology. Today's homes consume various forms of energy including Electric Grid, Solar Wind, Hydrogen Fuel based generators, Electric Vehicles, etc. Future homes will play role of energy consumer as well as energy generator. Smart Grid systems offer the intelligent optimization of power consumption by appliances, devices and electric cars and can turn off/on based on peak and off-peak based dynamic pricing. Excess energy will be fed back to smart grid and monitored remotely. This requires connected homes with control, automation and local/remote management features. Moreover, excess energy generated at home can be traded in real-time with other homes or back to grid, thus creating additional revenue streams or energy credits for the homeowners.

A third example involves the 24-hour on-demand work cycle for many mobile workers. For example, an employee attending a sporting event may receive an escalated work message and suddenly need to leave. The user should be able to seamlessly continue watching the game on his/her mobile device (Smartphone, iPad, etc.) while on public transportation to the office. If leaving in his/her car, the employee should be able to have the game follow them into the car and video will adapt to the viewing situation, perhaps by sensing and switching to audio only for the driver's safety. And the sequence can continue once he/she heads home and wishes to stream the rest of the game to their in-home devices. A similar scenario can play-out if the content is a live WebEx-like conference that can be experienced seamlessly as one moves from car to train to office and device to device, upgrading from mobile call to laptop video, to TelePresence, etc.

In a fourth scenario, the homeowner would like to monitor the safety his/her home from inside the home, from the car or any remote location.

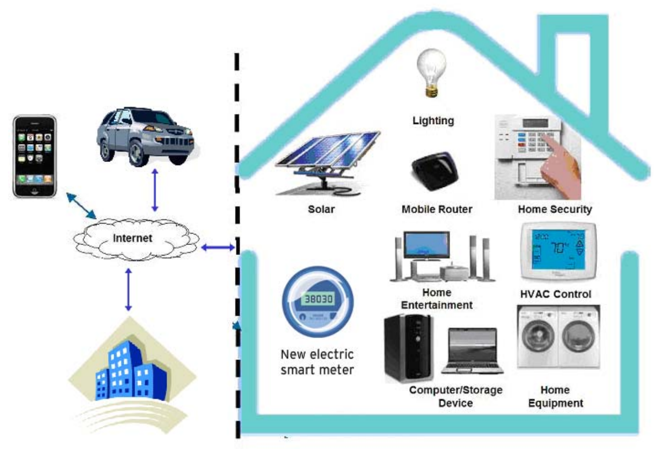

Figure 4: Pervasive Connected Home

The above scenarios are just a few of the many examples one can imagine in a pervasively connected environment. Homes are a prime example of devices participating in the Internet of Things, where, everything at home- from a light bulb to a refrigerator- will be connected and in many cases be IP-enabled. What that means is everything at home can be connected to the rest of the world in a pervasive and intelligent fashion, yet achieving interconnectedness will require a pervasive platform that allows for secure interoperability and continuity of experience across the many participating edge devices, applications, and services.

Figure 5: Pervasive Emergency Response

In fact, achieving a smart connected home requires intelligent software agents on every connected device, including sensors at home and its eco-system, irrespective of device hardware or OS type. These intelligent software agents should discover each other spontaneously and create secure and trusted clusters/communities of interest. Further, they should be able to intelligently and autonomously communicate context and data with each other in a peer-to-peer or peer-group or group-to-group manner in order accomplish a task/goal through cluster based/collaborative computation, data mining and data fission/fusion. Tasks are accessed, monitored, facilitated, shared, and empowered to collaborate with anything from anywhere at anytime.

E. Pervasive Emergency Response

During an emergency response or security scenario (see **Figure 5**), a mobile application that provides reliable unified communications and location mapping is a great asset to resource coordination. Emergency personnel can form an ad hoc community based on their role (medical, police, fire department, equipment, etc.) to route emergency teams effectively.

A pervasive application can also extend to vehicles involved in an accident that deliver persistent personal health record information for the driver. With proper security clearance (a medically authorized node), this information is accessible by emergency personnel to assist with medical attention. These information workflows further ensure transmitted electronically to the hospital using the same application.

VIII. CONCLUSION

It is evident from these scenarios that a pervasive platform that meets the requirements above, will enable advanced applications and services that are at their core, distributed knowledge, problem-solving networks with ad-hoc participants using multiple/different devices, spanning multiple groups, over multiple wired/wireless networks and integrating with various types of clouds.

The need for this cross-federated pervasive platform for interoperability, sharing, collaborating, and seamless follow-me content and services is well-known and is vital to many public and private entities. From safety and security, to climate monitoring and resource management, to urban planning, development, and management, to connected homes, and so forth, we must address communication and collaboration beyond the firewall and beyond centralized cloud architectures to achieve the right level of capabilities and experience.

The thought leadership at two of the biggest companies in IT— Cisco and Microsoft— and the scope of the scenarios they have outlined reinforces the points of this paper, some of which are actual works in progress. There is no doubt that these applications will come to fruition and change the way we work, live, play, learn, and perhaps change the very future of our planet!

Such a pervasive platform is much closer to reality than many may realize, so its time to start eliminating the barriers to these world-changing applications and network-composed services that are ripe for development. As a result, the world will be a better place, the quality of lives in so many aspects will be greatly improved, and not-coincidentally, wealth will be generated by those who seize the day. Carpe Diem!

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