How to Intelligently Build an Internet of Things (IoT)

Brief History of the Future

The Internet of Things (IoT), Internet of Everything (IoE), Big Data, Machine-to-Machine (M2M), and related concepts are all generating an increasing amount of hype. The high tech industry is looking beyond mobility to ***ambience***: sensor-enabled systems of systems are transparently enriching peoples' lives within a seamless set of intelligent environments. One good example of IoT vision is Corning's depiction of "ubiquitous displays" in their February, 2011 video, A Day Made of Glass.

Just as the "paperless office" concept, first floated in the 1960s and 1970s, is only now becoming reality, this new vision of ambient interactivity and intelligence is very much in its infancy. IoT will likewise take decades to mature. What is different today is that we have a strong cautionary example fresh in our collective consciousness.

The organic, unplanned, and ***unanticipated*** growth of the PC, Internet, and the World Wide Web gives us ideas for where we should design systems differently for this next generation of infrastructure. We've all spent too much of our personal time managing PCs and other devices to keep them configured properly, up-to-date, and protected from malware—never mind those random moments of panic when it becomes apparent that we've lost data, or despite reasonable precautions we've been hit by malware. If you run an IT department, an online service, or a hosting center, you have seen that play out far more frequently and on a much larger scale.

Current methods for managing enterprise IT infrastructure will not scale to meet the demands of IoT's systems of systems.

Early frameworks for this visionary universe of ambient, sensor-enabled systems of systems are mostly focusing in on vendor-specific issues. They are either too ***narrowly*** scoped: sensors, Big Data analytics, data connectivity, transport and security, managing complex systems of systems in the field. Or they are too ***broadly*** scoped: ill-defined, and are overreaching to define too many attributes of these systems…attributes that have not yet been adequately envisioned.

The challenge is to start with end-to-end services delivery in mind, while leaving room for technology and market evolution and innovation-driven value over the next few decades. The concept of "Intelligent Systems" is emerging as a way for today's infrastructure vendors to create a useful market structure and compete in key components of these embryonic end-to-end services.

Defining Intelligent Systems (IS)

There are many definitions of IS. That is to be expected as vendors jockey for position at the start of a major new market opportunity. However, lack of a commonly accepted definition will confuse buyers and stall market development.

Moor Insights & Strategy proposes this definition of Intelligent Systems:

- *Internet connected:* Adheres to standard Internet protocols as they evolve
- *Intelligent:* Runs user-mode applications
- *Managed:* Monitor and configure over the Internet
- *Secured:* Encryption and authentication for management and communications; threat and malware detection and resolution
- *End-to-End:* Consistent service interfaces span the ecosystem

Internet Connected. It seems like a given, but it is not. Many sensors, in particular, will not be directly connected to the Internet. Direct Internet connectivity will be determined by use cases for cost, power consumption, security, and a host of other issues (including private innovation running ahead of public standards). Many sensor manufacturers will design their products to form their own private networks. The likelihood that every sensor or even every client device will aspire to full Internet citizenship is vanishingly small. This enables the "systems" part of IS.

Intelligent. The ability to run user-mode applications implies enabling hardware platform architecture (the ability to run a modern OS and runtime environment) and a viable software development ecosystem. This enablement is, by definition, the "intelligence" in IS. There are no hard rules on which platforms will need what level of hardware support for app performance…even in the near-term. That said, designers have a good idea of the performance required to run an OS and runtime environment, and to provide memory and I/O resources for the apps that will run in those environments. Nominally, an intelligent component of an IS will be able to perform tasks such as managing itself and sensors, plus aggregating, filtering, and perhaps summarizing data from sensors. Analyzing data from various levels of data aggregation is a cornerstone of IS capability. But analysis is increasingly optional as a device moves closer to the edge of an IS, *i.e.* gateways and clients, and then past the edge into sensors that do not perform analysis.

Our definition of "intelligence" is broad by intention. We intend it to cover a spectrum of devices, from client platforms containing both app processors and built-in sensors to hyperscale datacenters designed to coordinate and manage massively scalable services. But, as mentioned above, enumerating specific apps or workloads as part of this definition is limiting, given the early nature of the market.

Managed. Every component in an end-to-end service must be capable of remote configuration as well as health and status monitoring. An IS must be able to achieve this ***over the Internet***, as opposed to other components that maybe be managed over private networks. Remote configuration includes completely reimaging the OS and

system software and managing user-mode apps. It also comprehends scheduling apps across a larger scale system.

Secured. These systems are communicating across what today is an inherently untrustworthy Internet infrastructure. So encryption and authentication are mandatory for storage, communications, and access to management functions. This security requires a higher level of capability than might be implemented in a closed, vendor proprietary network of sensors. Threat assessment and malware detection and resolution are likewise table-stakes across the spectrum of IS capabilities.

End-to-End. The concept of an "end-to-end" service has been lost in many of the definitions. Scalable services are built from defined and consistent service interfaces; new products (hardware, software and combinations in the form of appliances, robots, *etc*.) "snap-in" to a standardized services interface framework. Consistency is important to simplify the debugging and deployment of large-scale systems of systems, especially with respect to managing and securing inherently complex networks and device hierarchies.

We purposefully exclude some popular topics from our definition…

People vs. Machines. New mobile form factors are generating a lot of location-based data, and Big Data driven natural user interfaces are interesting. But focusing on them to the exclusion of M2M and IoT seems short-sighted. Examples of attributes under this topic that we do not explicitly cover:

- *Web browsing:* Already comprehended by both Internet connectivity and intelligence. Not something a home medical device (as one example) would be likely to do.
- *User interface:* More general than web browsing, and simply not needed in M2M.

Native vs. Cloud Based Applications. This is an artificial distinction between user-mode apps running on a client device and user-mode apps running in a datacenter. We believe that all IS must be able to run user-mode apps. Once a client device is connected to the Internet and running user-mode apps, it can take advantage of remote cloud services (and vice versa). After a couple of decades, app runtime locality will most likely be a non-issue.

Big Data and Analytics. Everyone wants a piece of this, but it represents one class of user-mode applications, and an IS doesn't necessarily do analytics. Big Data and Analytics are following the path of Cloud as the next "must use" terms to describe products. Their ubiquity is reducing their usefulness as precise descriptive terms.

The impact of poorly coordinated standards across IS systems will be unneeded complexity and balkanization of vendor ecosystems and products—which directly translates into buyer confusion and stalled market development.

The Early Competitive Field

The stunning success of smartphones, followed by similar success for tablets, has pushed the standardization opportunities for next generation infrastructure into play for the top tier of visionary companies. For the most part, their postures seem somewhat hurried.

IBM Smarter Planet has identified relevant IoT real-world issues for vertical markets and has what looks like a large marketing and consulting effort aimed at vendors in those verticals. However, we have yet pinpoint a singular infrastructure vision. IBM is communicating in terms of complete solutions without communicating a common infrastructure vision or theme across solutions. IBM's research folks are funding university and open source R&D, such as their Mote Runner platform specification (still in beta). These investments are meant to encourage other vendors to build compatible platforms. But IBM seems to be open to a wide range of technical and architectural interoperability—which adds complexity and reduces performance, reliability, security, *etc*.

Cisco's Internet Business Solutions Group is in the Internet of Everything (IoE) camp—IoT being, apparently, insufficient. Borrowing from Metcalfe's law, they sensibly state, "*Network effects are at the heart of IoE.*" Cisco counts as network effects not only interactions between people, things and data, but they also count people-to-people (P2P, not to be confused with peer-to-peer) and people-to-machines (P2M). Cisco started their IoE media push in late 2012 and promised a "Cisco Connections Index" to track their network-centric view. Since then, we've heard more about their Visual Networking Index which introduces the The Zettabyte Era, but have not heard more about their Connections Index. We believe that networks are not ***all*** that is at the heart of IoE.

Microsoft Intelligent Systems seems aimed at incremental Windows Embedded sales. Similar to IBM, Microsoft identifies several viable vertical industries. Also similar to IBM, Microsoft appears to lack a focused infrastructure vision. Microsoft's cloud offerings along with existing Windows IT systems are meant to be the backend to the Windows Embedded devices.

Google researchers are spread out through the IoT world, and they are funding other folks' experiments. But there doesn't seem to be much coordinated work going on at Google focused on IoT. It's hard to find out, given the shutdown of Google Labs in July 2011. Google would appear to have the potential to cover both ends of the infrastructure continuum from Android OS to the Google Cloud Platform.

GE's Minds + Machines initiative is a wildcard. GE is large enough to affect the direction of the industry, should they choose. GE recently expanded their analytics partnerships with Accenture and Amazon Web Services (AWS) under the banner of "Industrial Internet" but in support of GE's own hardware products. It is less clear if they are willing to collaborate with the broader industry regarding what GE is calling "Brilliant Machines": sensor-enabled products and aggregation points that drive end-to-end services when combined with the industrial Internet.

IPSO Alliance (Internet Protocol for Smart Objects) formed in late 2008 to promote the use of IP in smart objects: sensors and other end-points. IPSO does not define technologies, but instead documents how existing industry standards might be used and works with industry standards organizations to promote features friendly to smart objects. They distribute prize money, "to both promote and contribute to the development of the Internet of Things." The ISPO Alliance's underlying assumption is that all smart objects should connect via IP, which we don't believe should be a foregone conclusion. Their work does not address the larger issues of IS.

ARM talks evocatively of "wearable, ingestible, implantable" sensors as well as massive server installations. Thus far, they seem focused on sensor networks via Weightless, agreements with telcos for M2M communication, and a UK industry forum. Still, ARM has not announced a more comprehensive end-to-end vision.

International M2M Council is a new, global trade association to connect vendors and adopters. IMC will not develop technical specifications either. Instead, they intend to publish use cases and benchmarks including the Adopter Benchmarking Index.

HP M2M Solutions is focused on M2M communications and not yet focused on an integrated IS strategy.

Qualcomm is in the IoE camp and is similarly focused on end-points and M2M communications without including the larger IS picture.

We are unaware that **Dell** is doing any work aimed at IoT infrastructure.

There are two organizations that are assembling end-to-end visions of IS:

IoT-A (Internet-of-Things Architecture), formed in 2009, is a European Lighthouse Integrated Project. We give them good marks on completeness of vision and being forward looking. IBM Research is working with IoT-A. However, IoT-A is attempting to lock down a massive scope of standards perhaps too early in the industry's development. As stated above, too much standardization too early in the process will stifle innovation.

Intel's Intelligent Systems Framework (ISF) is a forward-looking framework for describing the baseline capabilities of, and interactions between, IS systems of systems. Intel's scope is broad, but it is more focused than IoT-A. Intel's goal is to enable organizations to deploy solutions in the near-term that will evolve as new technologies and new standards continue to evolve. ISF is focused on all of our core attributes of IoT. They concentrate on the technologies and interoperability required by a COO to operate at-scale infrastructure for factories, stores, and other non-traditional IT deployments.

Intel is leveraging its traditional enterprise CIO customer base into new IoT infrastructure markets—markets where COOs are in charge of deploying datacenters

and networks of sensors. Intel has succeeded at this cross-pollination before in other markets. Their success shows they are paying attention and that they intend to build on their already dominant IT market position.

Scope of Intel's Intelligent Systems Framework

Scope	Role	Public Cloud	Intel ISF			Embedded Client	Sensor	
			Cloud	Gateway	Client		Smart	Connected
Single Device	Sense real-world data				O	O	x	x
	Connect to Internet				x	O	O	O
	Filter data, summarize				x	x	x	
	Aggregate sensor data				x	x		
	Analyze data and initiate local actions			x	x	O		
Spans Multiple Devices and Systems Across Internet	Legacy comms and network hub			x				
	Reside on Internet		x	x				
	Unified manageability		x	x	x			
	Unified security		x	x	x			
	Unified network app scheduling context		x	x	x			
	Aggregate and filter sensor/endpoint data	x	x	x				
	Big Data analytics	x	x					
	Initiate systemic actions	x	x					

O=optional

Getting Started with IS

As you evaluate overlaying IS and Big Data analytics onto existing infrastructure—or the build-out of entirely new M2M and IoT infrastructure—it is critical to consider that this market will undergo massive change over the next decade:

- The sensor market will be a Darwinian stew of evolutionary experiments.
- New network and storage hierarchies will evolve to manage the accelerating inflow of increasingly rich data from growing sensor deployments.
- New datacenter technologies will come online to analyze and react to the sensor data flow in real-time.

Vendors will be vying for IoT, IoE, M2M, *etc*. to position themselves over the next couple of years. We recommend a couple of initial directions:

Tap into sensor innovation. Sensors are expendable and replaceable, especially considering the rapid increase in capabilities we expect through the end of this decade. Treat them as such and do not lock into long-term directions yet.

Focus on end-to-end basics for IS. Deploy intelligent, manageable, and secure intelligent systems that will absorb the data from and manage your sensor networks. Pay attention to emerging frameworks and standards. Stay flexible, but watch for increases in complexity that can result in management headaches and non-deterministic service behavior.

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