RFID and Sensing in the Supply Chain: Challenges and Opportunities

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Radio Frequency identification (RFID) is a mature technology, but for reasons of cost and size, its use has been restricted to a closed set of applications. However cost reductions and efforts by EPC Global and industry giants, such as Wal-Mart, are causing the supply chain industry to shift towards broad adoption of RFID technology, based on emerging open standards. This is creating a large business opportunity for HP.

At present, the Electronic Product Code (EPC) framework is focused on inventory and distribution management. This paper describes a HP initiative to enhance the framework to provide safe, secure and adaptive supply chain solutions. Such solutions require knowledge of the 4Ws – Who, What, When and Where. RFID provides the Who (ID), and research activities within HP Laboratories are investigating an adaptive sensing infrastructure approach to providing the What, When and Where. An environment adhering to this approach can develop sentient capabilities; becoming responsive and conscious of its state, to ensure that goods are not only in specific locations, but also determine their actual conditions.

Current market solutions are often based on reader infrastructure, where the intelligence is at the edge of the network. As the density of sensing (in space and time) increases, the information collected will potentially overwhelm the network. Our Sentient infrastructure pushes the intelligence to the end points – close to the readers and other sensors – where the information can be filtered and aggregated in situ, reducing the [shared] wireless network traffic. The components create a self-configuring system, resulting in lower deployment and testing costs. Due to the adaptive nature of the infrastructure, the environment is resilient to sensor failures and tolerant of malicious attacks.

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Abstract

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1. Background

Radio Frequency Identification (RFID) is a method of identifying unique instances of items using electromagnetic energy. RFID tags contain digital information that is conveyed upon interrogation by a reader. RFID is a mature technology, but its use has been restricted to a relatively small number of closed loop applications, such as security badges, due to cost and size limitations. The efforts of EPC Global, its member companies and other organizations have resulted in standards for end-to-end data capture and usage. The influence of Moore's law on tag prices, combined with mandates by industry giants such as Wal-Mart, are causing the industry to shift towards adopting open standards based RFID. The potential applications are far reaching, from manufacturing right through the supply chain to retail; from cradle to grave. Initially, most companies are expected to focus on *upstream* supply chain operations such as distribution and inventory management, especially at the case and pallet level. However, follow-on applications will emerge to embrace the whole of the supply chain, just as barcodes did 20 years ago.

Wal-Mart's RFID mandate requires their top 100 suppliers to tag shipments, down to the casing and pallet level, prior to delivery. Hence, supply chain management for consumer packaged goods (CPG) is the present focus for EPC Global and its members. We expect other industries (e.g. automotive, hi-tech and pharmaceuticals) to follow suit. We also foresee interest in item level tagging, predominantly from companies trading in high value items (e.g. Chanel or Christie's). Other entities (for example, the US Department of Defense) issue RFID tagging directives to their suppliers. This is a very large business opportunity for HP.

HP is well positioned as both an end user (with a very large global supply chain) and as a leading technology, consulting and integration solutions provider. In particular, our adaptive approach will be a key differentiator in this industry as each business case will encounter differing environmental conditions, equipment and software components from a multitude of suppliers. Neither IBM nor Accenture can offer this combination of capabilities and breadth of experience.

2. EPC Global

Efforts to standardize the various system components for RFID were initiated by the AutoID Center. This work has matured with the creation of the electronic product code (EPC) standard, administered by the EPC Global organization [1]. The standards specify not only the tags and readers, but define methods and protocols for data processing and connectivity to IT infrastructure.

Table 1: Existing and proposed EPC Tag classification types

Tag Class	Description	Power Source	Communications
0	Read Only ID Tag	Passive	Backscatter
1	Write Once / Read Many ID Tag	Passive	Backscatter
2	Read / Write Tags with extended functionality (e.g. Encryption, addressable memory)	Passive	Backscatter
3	Semi-Passive Tags (i.e. improved read range)	Passive / supplementary battery	Backscatter
4	Active Tags (e.g. sensor network nodes)	Battery	RF Transmission / Reception
5	Powered Nodes, essentially readers	AC	RF Transmit / Receive RF Energizing Field

EPC Global plans to introduce progressively more capable tag classifications from 0 through to 5. Table 1 summarizes the EPC tag classifications. At present, first generation class 0 and class 1 tag standards have been commercialized, with read only and write-once variants. Simplicity and low manufacturing costs are the primary drivers for the lower tag classes. Work is in progress to ratify second generation tag standards, with product releases expected in 2005. These tags will have an *orthogonal* air interface so they will not interfere with existing tags, but will not be directly compatible. However, it is expected that the second generation air interface standard will be adopted across tag classes 1 through 4, easing the future introduction of the higher tag classes and compliant readers.

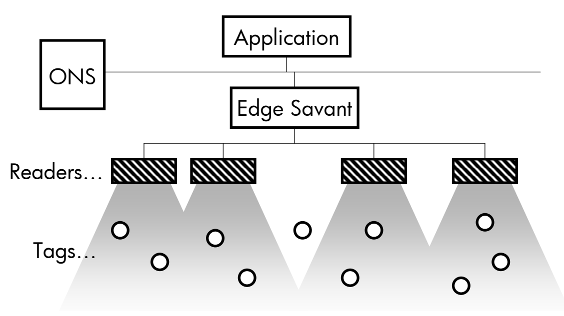

Figure 1: The EPC Global data collection architecture

The EPC Global data collection architecture (shown in figure 1) defines protocols and services, including edge servers or Savants (EPC data aggregators), Object Naming Services (ONS), a Product Markup Language (PML) and other related specifications. Edge Servers are deployed as data managers for one or more readers. They perform data smoothing, reader coordination, data forwarding and storage. Edge servers are filtering gateways, removing redundant network traffic and only forwarding relevant or requested information to upstream applications. The ONS server performs a look-up service, relating the products EPC identity to the location where information about the product is located. This information is usually hosted by a second service known as the EPC Information Service or EPC-IS. This uses XML compatible descriptors (known as the Product Markup Language - PML) to format, store and process product information. EPC-IS also provides a standardized method of information exchange between EPC services and business applications.

3. Problem Statement

The EPC framework is designed with the express intention of enforcing standards only where necessary. This approach suits the industry, by providing opportunities for technology companies to innovate.

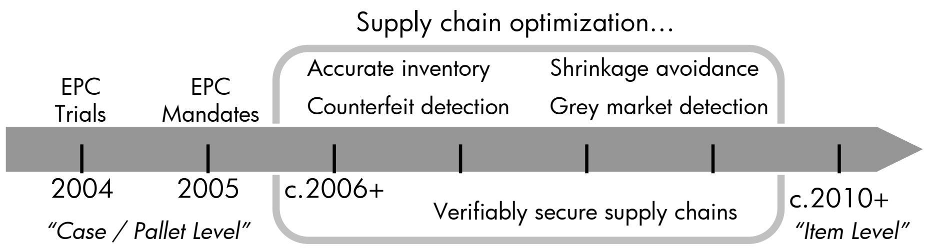

Figure 2: The EPC / RFID Adoption Timeline

Consumer package goods and retail companies, which lead the adoption of the EPC architecture, are driven by improvements in distribution (automated shipping, receiving and palletization) and shelf stock outage reduction. However, as shown in figure 2, future RFID adoption will address other key areas of supply chain optimization. These optimizations go beyond the current *slap and ship* model to encompass secure and reliable delivery of goods, brand management through counterfeit and gray market detection, shrinkage avoidance and accurate and autonomous unit level inventory management. Such applications will require knowledge of the four *W'*s – *Who*, *What*, *When* and *Where*. RFID attempts to answer the question *Who* (an object's ID). However, obtaining the remaining *W'*s requires a pervasive infrastructure with vastly improved sensing capabilities. This need raises a number of distinct issues, which the present EPC initiatives do not fully address. These include:

Multi-modal Sensing: The question *What* (an object's state) requires additional sensors that are not part of present solutions. *When* and *Where* require precise time and location. While time maybe obtained using the Network Time Protocol (NTP), location – in present solutions – is only coarsely provided when tags are within range of readers at known locations, which maybe acceptable for a small number of readers. For larger deployments, location determination becomes a more arduous task, further complicated by mobile readers.

Security: To minimize costs, EPC Class 0 & Class 1 tags do not have cryptographic capabilities and transmit ID's in the clear, limiting tag-reader security and allowing external parties to acquire information. Protection of aggregated data is of more importance and can be addressed by encrypting data that emanates from the readers. However, security has not yet been addressed by the EPC framework. As a consequence, present generation solutions are weak in this area.

Resilience: EPC tags, readers and network infrastructures are subject to failure. The limited resilience designed into present designs allows minor problems to create disabling effects. This is important not just from a 'box' perspective, with the potential to seriously impact business operations, but also from the view of protecting a supply chain's integrity from malicious attacks.

Ease of deployment: Present RFID implementations require a significant degree of skilled deployment, in terms of reader placement, tag positioning, environmental testing and IT integration. At present, automation toolkits to address deployment and configuration complexities do not exist. The regional variations in frequency allocations and reader power levels make implementation of truly global tagging solutions difficult, despite global standards for data formats and encodings.

Scalability: RFID infrastructure can generate large volumes of raw data. Adding other sensors will vastly increase the environments data density. This can easily overwhelm the network and backend applications. However, the current EPC edge server implementations centralize RFID data aggregation and are ill-suited to processing additional streams of sensor data. This approach is neither adequate nor scalable.

Manageability: In more dynamic environments such as warehouses, where the sensing elements are far from virtualized, a network view of the equipment is insufficient,. Their physical location is an essential aspect of the data set. Management tools that co-relate physical location, sensing equipment and sensor data are in an embryonic state, and without such tools, locating, servicing, and estimating failure impact is cumbersome. Many of the tools and technologies that form RFID infrastructure solutions were never designed for outdoor and warehouse conditions. These are not ideal IT environments and thus a new approach is required.

In many respects, present RFID supply chain solutions provide a fragmented (*ID-centric*) view of events, only registering the presence of tags when they are within range of compatible readers. To create a more holistic and representative view of the supply chain will require more than just ID labels. In the future, the ID's may become the lowest common denominator in an information rich data set, from which spatially orientated and environmentally aware virtual representations of the whole supply chain can be generated in real-time.

4. RFID and the Adaptive Enterprise

The adoption of RFID throughout the supply chain can provide two main advantages to the enterprise. Firstly, it improves the visibility of inventory and demand level predictions throughout the supply-chain. Secondly, via track and trace processes, it provides additional security through shrinkage avoidance, grey market diversion and black market counterfeit cloning. Improved visibility and security of the supply chain will benefit the overall business, directly by more optimized and efficient production and distribution flows, and indirectly through improved brand protection and certainty of produce. RFID has the potential to create a truly adaptive supply chain, enabling all aspects of the business cycle (production, storage, distribution, retail and returns) to be monitored in real-time, optimizing for present conditions and making predictive changes based on expected demands.

The adaptive enterprise approach to business computing encourages the pooling of IT resources to improve their utilization and avoid over-deployment. Sharing IT resources across business functions helps to increase business agility, enables rapid provisioning of new resources, and scaling of established services. Figure 3(i) shows the layering of business functions. Computing resources support higher level functions through virtual abstraction. This provides an agile synchronizing infrastructure, able to relate business strategies to process implementations and application services through automated and intelligent management and provisioning of IT resources.

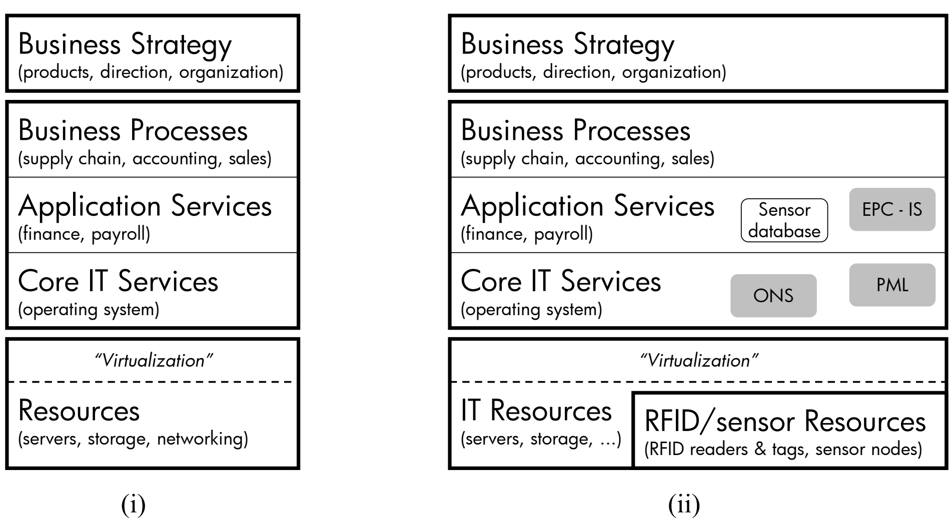

Figure 3: Adaptive enterprise stack (i) and the insertion of physically dependent resources (ii).

RFID system implementation is as much a physical process of installing readers, tags and other physically based infrastructure as it is an IT integration issue. Incorporation of RFID related software components with existing infrastructure fits well with HP's adaptive architecture. However, virtualization at the RFID and sensing level is somewhat more constrained by the physical environment. As an example, if a server is overheating, perhaps due mechanical failure of a cooling fan, processes can be re-spawned on another server and new tasks re-directed. However, it would be difficult to regenerate the results from a failed RFID reader as it is unlikely that other readers will occupy the same physical location and completely overlap the missing reader's coverage. Therefore it would seem prudent to separate the resources that are spatially dependent from those that can be re-assigned to other machines. This is illustrated in figure 3(ii), where the enterprise resources have been suitably partitioned. The natural association of sensing systems with the spaces they occupy and the real-time data they create means that they cannot be virtualized using existing tools; knowing that the temperature is 50 degrees, for example, means little without knowing the context and location of the measurement. Such spatial dependencies also impact the system's fault tolerance. If other sensors are not available at the same location, the system may have to rely on adjacent measurements or on statistical modeling to continue effective operations.

Integrating RFID throughout a complex supply chain is a major undertaking, requiring the elimination and replacement of established practices. Given the effort and costs involved, we expect the adoption of RFID to be an incremental process, building on the initial customer mandated requirements towards more sustainable benefits for the enterprise. As this build out continues, we believe this will create demand for HP's Adaptive enterprise offerings as customers scale and optimize their RFID based supply chain operations.

5. Our Solution

In the Sentient Environments group at HP Labs, we are performing research into techniques and technologies to enable the creation of truly adaptive supply chain solutions. Within this context, we are pursuing an adaptive, heterogeneous sensor network based approach to RFID infrastructure. The Sentient approach is compatible with the EPC Global initiative, adhering to the defined protocols and specifications. We rely on the same third party EPC tags, readers and higher level system components. Our solution provides additional components that are not only capable of addressing the 4*W*'s, but also address many of the short comings of present day RFID infrastructure solutions.

Typical RFID system installations provide limited visibility, since they can only track tags within range of the reader ensemble. This results in discrete zones of readability. These are often created by placing reader's line-side in manufacturing, around dock doors and at strategic points in the physical flow of goods through operations. Tagged cases and pallets are then read as they enter or exit the warehouse. In a large warehouse it is not currently cost effective to ubiquitously deploy readers and so even large cases and pallets, once inside, can be lost within a known area of operations. In our solution, an overlay of additional sensor systems and technologies address these limitations by correlating multiple data sources to provide a better view of the environment's state. Figure 4 shows an outline of our Sentient approach to sensing in the supply chain. This retains the EPC Global data collection entities, but makes significant additions to enable a diverse range of additional sensing capabilities. For example, we have developed low overhead embedded computer vision algorithms that can visually track cases and pallets after their ID is read by a RFID reader. Even in cases where occlusion takes place, the system can gradually re-identify the objects.

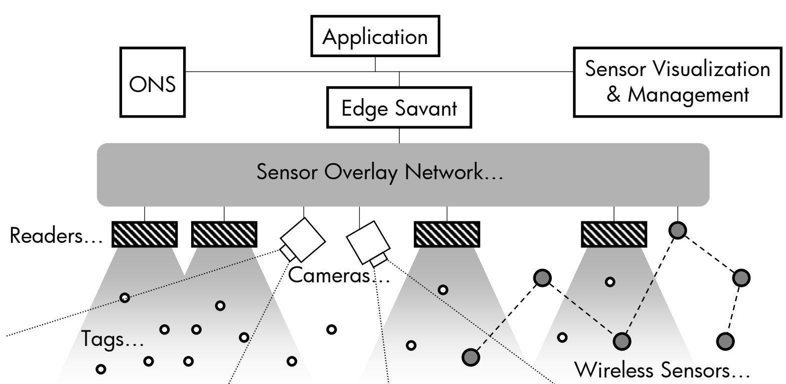

Figure 4: Adaptive-infrastructure enhancements to the EPC architecture

Our Sentient approach inserts a hierarchy of diverse ad-hoc wired and wireless network structures and computing nodes that are capable of processing and filtering both sensor and RFID data. Together, these form a *Sentient Overlay Network*, which provides an adaptive sensor and network abstraction layer that operates on top of this heterogeneous network. RFID readers, along with other types of sensors, are easily attached to this network, enabling sensor fusion. Time synchronization between the nodes is done using protocols developed elsewhere. Custom in-house and third party solutions append positional information, allowing suitably equipped nodes to localize themselves in space. The Sentient approach also includes components that address security and manageability issues. The following sub-sections describe the main components and attributes of this evolving system architecture and component technologies.

5.1 Platforms and Networking

To implement our Sentient sensor architecture, we adopted a loose hierarchy of three distinct computing platform types (shown in figure 5), which match the computation resources of readily available computing and sensing components. These are broadly classified (from top to bottom) as Computing Nodes (CN), Powered Nodes (PN) and Micro Nodes (MN). Inter-nodal messaging is performed using a diversity of wired and wireless communication methods. Figure 5 also shows the device connectivity for an example configuration.

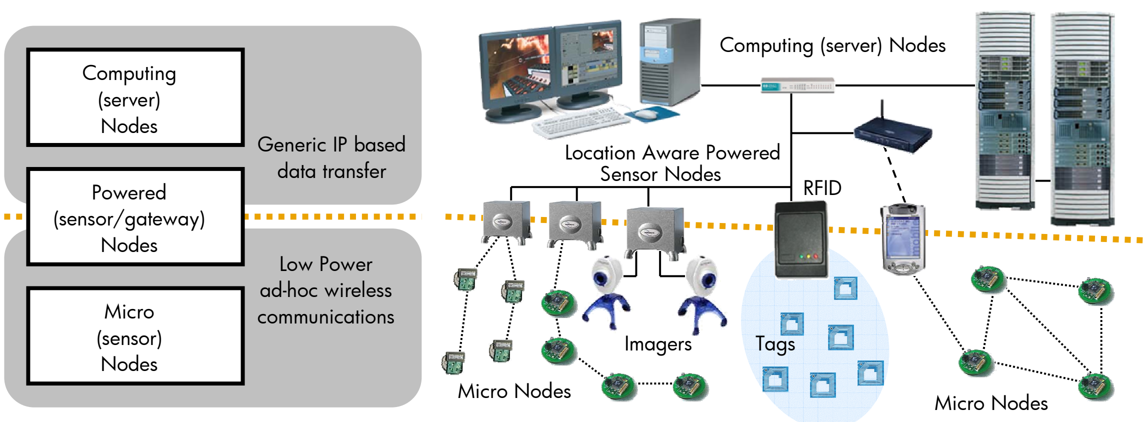

Figure 5: Sensor Platform Hierarchy – Example Device Configuration

Micro Nodes perform the sensing, initial processing and communicate using ad-hoc networks to provide flexibility of deployment and nodal mobility. Such platforms include miniature wireless sensor nodes, for example the Intel/Berkeley Motes and the HP Labs developed Locus system of location aware sensor nodes. These are primarily low power, resource constrained and battery powered devices. Powered Nodes are primarily designed to operate at fixed locations as they require wired connections, either for power and / or bandwidth connectivity. These may include RFID readers, security cameras and embedded computing nodes. Such powered resources have superior computational capabilities and so often function as gateways – collecting and aggregating data from adjacent Micro Nodes before passing this to higher level services. Computing Nodes host the Sentient software components that work alongside other IT services. The computing nodes do not perform any physical sensing and thus their location dependence is significantly reduced. This allows their virtualization, resource re-allocation and implementation using industry standard IT building blocks, for example, industry standard servers and network routers.

Network communications follows a similar hierarchical divide. The upper layer communication use generic standardized wired IP based solutions and wireless LAN (e.g. 802.11b/g) where appropriate. The lower layer communications are predominantly wireless, however standards (e.g. Zigbee, wireless USB) in the sensor networking space are still evolving. At present different device clusters within our implementations use a selection of *sub-IP* low power ad-hoc short range RF communications types; although in time we may converge to and adopt the a prevailing standard as this area matures.

5.2 Positioning Technologies

A major distinguishing feature of Sentient systems is their ease of deployment and operation, which – in an ideal case – would be a wholly automated process. To enable self-sufficient configuration and management, the physical location of all the spatially dependent system nodes is required. For fixed nodes, this could be embedded into the device during initial configuration. However, nodes often possess variable degrees of mobility and so an automation of this process is required.

Table 2. Summary of different positioning methods

Method	Description	Range	Resolution
RF	Carrier based radio propagation (e.g. signal strength, time of arrival, angle of arrival,)	30-300m	2-10m
UWB	Direct / impulse radio propagation (speed = $3x10^8$ m/s) (time of flight measurements – leading pulse / edge detection)	10-30m	30cm-1m
Imaging	Digital image capture and processing (passive feature detection, or active source identification)	10-15m	5-10cm
Acoustic	Time of acoustic propagation (speed = $3.65x10^2$ m/s) (time of flight, phase difference for angle of arrival)	10-15m	1-5cm

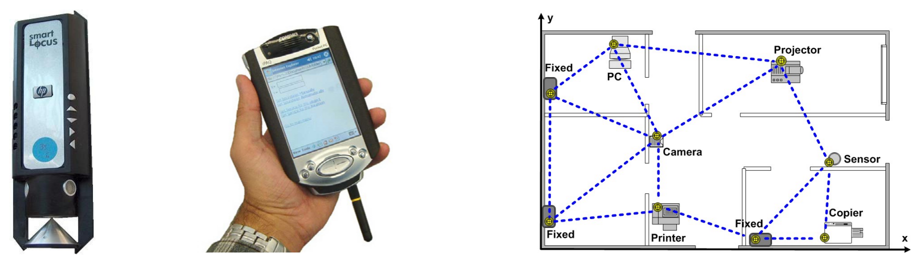

Figure 6: The Locus embedded computing and positioning nodes

We have reviewed and are actively investigating a suite of indoor positioning techniques for insertion into our sensing systems. Table 2 summarizes the main positioning techniques. RF methods monitor radio propagation parameters (e.g. signal strength, time and angle of arrival). GPS is the most widely adopted location method, with global coverage and an unassisted accuracy of 10 meters. Ground based correction data improves this accuracy to 2 meters, however indoor satellite reception is extremely difficult to achieve. Hence other approaches must be considered for indoor positioning. Cell phone triangulation is possible, but with poor resolution, often only to the nearest building. Wireless LAN access points can be modified to provide location determination within buildings [2], with an accuracy of 1-3 meters. In general, the propagation path within indoor environments is complex, multi-path and time varying, making accurate positional determinations difficult. Ultra-wideband (UWB) radio offers the potential to overcome these limitations by using time based impulse modulation techniques together with accurate pulse propagation timing. Sub-meter accuracies have been achieved by a number of prototype UWB positioning systems [3]. However, the present FCC restrictions on usable bandwidth and power levels reduce the estimated operational range to around 30 meters.

In many cases, meter range resolution is adequate. However, in cases where centimeter level resolution is required, alternatives to RF must be considered. In this regard, we are investigating imaging and acoustic methods. We have developed a distributed camera based tracking system, for passive objects or actively tagged items with an identifying light source. Our acoustic ranging system, called Locus, measures the differential time of flight between an RF synchronization signal and an acoustic ping, with a resolution of several centimeters. Figure 6 shows our prototype infrastructure and mobile nodes, together with how they could be deployed in an office environment. The main problems with acoustic signaling are absorption and multi-path interference; where in secondary pulses can be miss-interpreted as the primary path. However despite these, acoustic positioning offers the best resolution of the available techniques.

5.3 Sensor Overlay Network

One of the unique characteristics of RFID and sensor based systems is physical dependence on their operating environments. However we wish to achieve a significant degree of virtualization within such deployments. Our approach inserts a sensor overlay network (SON) in between the physical sensing elements and the higher level applications. Essentially, the SON provides sensor, communications and programming abstraction, so that higher layer applications can be more consistent, easier to develop and shielded from physical and network dependent complexities. The major tasks accomplished by the sensor overlay network include:

Sensor Abstraction: System deployments often contain a multitude of different sensing elements, with differing capabilities and characteristics. Sensor abstraction classifies their attributes to expose nodal features to the rest of the system in a pre-defined manner. These attributes may include a unique node ID, the device's mobility, its power source and expected longevity, the type(s) of measurements the node can perform and their range, resolution and rate parameters.

Communications Abstraction: The lower physical network layers may consist of numerous clusters of, sometimes incompatible, low power wireless sensing elements. The connectivity of such networks often changes over time, particularly if the sensing nodes are attached to mobile objects. In such cases, it is important that the SON adapts to topological network changes and that it provides network and path independent methods for inter-nodal routing.

Sensor Programming: To remain adaptive to operational changes, the SON distributes rules to the underlying sensor nodes. These consist of semantic scripts that define the operations to be performed by the nodes.

Query Execution: The actions of each node depend on its capabilities, location and interpretation of received queries. These queries are executed by first matching the query to the nodes capabilities. If a match is found, the node will respond by answering the request; where appropriate it will also propagate the request to neighboring nodes, facilitating a query based search of the available resources.

Results Aggregation: Query matches that result in data responses propagate back to the query originator. If intermediary routing nodes can also respond to the query, the resulting data is aggregated within the network, avoiding duplication and reducing bandwidth and power utilization.

As a consequence of the sensor overlay network, system operations become *data centric*, with sensing, storage and information processing based more on the context and location of the queries than on the specifics of the individual sensors. Our implementation follows the three-tier nodal hierarchy described in section 5.1. However, the SON creates a mesh orientated view of the sensing components as shown in figure 7. Across each layer of the hierarchy, mesh based multi-path fault tolerant data routing is possible, allowing information to find an ad-hoc pathway to its destination in the presence of point failures in the network.

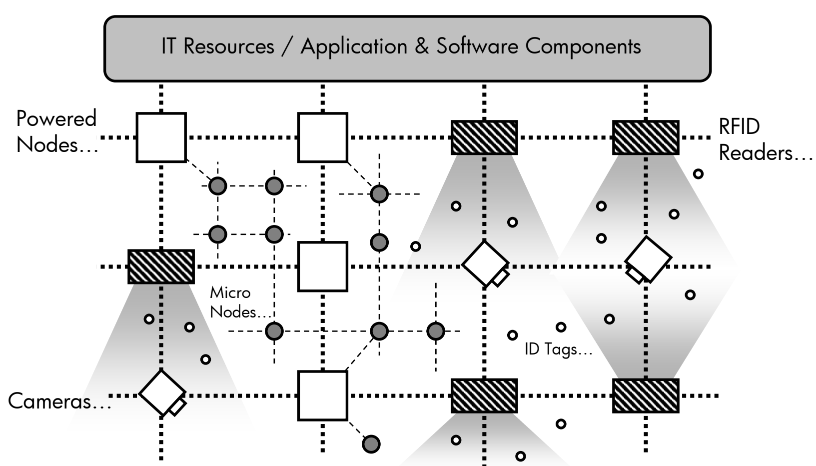

Figure 7: Sensor Overlay Network

5.4 Security

EPC Global has not adequately considered the problem of security, only recently forming a security working group. Their 2004 deadline is modest – to produce a white paper describing generic security challenges to an RFID based architecture. Specific case models, such as supply chain, will be considered at a later stage. In contrast, we have performed an analysis of generic threat models for sensor based architectures and considered threat models to specific applications. In general, within supply chains, two central issues emerge: anomalous boxes on pallets and the problem of missing boxes. Both of these issues are compounded by a third problem, the integrity of the readers. Often, they do not read all the tags that pass through their view. This phenomenon has to be distinguished from that of missing boxes. In this direction, we are looking at solutions based on error control codes to model these as erasure channels from which we seek to recover information.

To consider the use of cryptographic methods in RFID and sensor based systems, it is worth noting that asymmetric cryptography is justifiably precluded from wireless sensor networks, on the grounds of limited computation and bandwidth. However, it is conceivable that AC powered RFID readers could support these methods. Therefore, we could design solutions based on public key cryptography for supply chains. At the same time, active RFID tags and wireless sensor infrastructures could support light elliptic curve based cryptographic primitives, which require shorter key lengths than RSA or DH type cryptosystems for an equivalent level of security. These systems are also much faster and HP has extensive internal expertise in elliptic curves and their applications, making this research more fruitful.

At present, we are working on an integrated security solution that would fit into a generic architecture and software stack that we are concurrently designing. This would include, among other things, authentication, encryption and secure routing.

5.5 Management and Visualization

RFID systems track objects by reference to their tag ID values. The Sentient approach introduces correlating sensor data, providing a more featured representation of the environment. As sentient systems develop, we expect the data throughput to increase, potentially by several orders of magnitude. Under such conditions, it will become impossible for operators to effectively manage such systems by interpreting raw data streams. To address this concern, we have developed a visualization tool called Geo-view [4], which provides a sophisticated means to visually represent Sentient systems using 3D graphics technology. Geo-view renders complex data in a way that can be easily interpreted, blending RFID and sensor data with textured models of the environment in real time. This provides an intuitive and interactive view of the user's local environment.

Geo-view contains more functionality that it's graphical capabilities; the external view. Internally Geo-view provides the bindings between sensor nodes, their resultant data streams and their physical locations. In warehousing applications, for example, Geo-view can assist with diagnostics and reporting by allowing a remote operator to see a virtual instance of distant sites, through low bandwidth data links. This is possible, as the rendering of physical objects, their status and location within each environment is performed at the operator's location.

At present, we have applied Geo-view to the HP Labs Utility Data Center [5]. In future, we plan to use Geo-view's programmability and visualization capabilities to improve the certainty of business actions and to reduce complexities of asset management and security. Allowing users to monitor and react to asset changes through a virtual 3D interface reduces the complexity of managing the individual links of a supply chain. We believe this will become a useful addition to HP's Open-view suite, particularly for management of RFID infrastructure.

5.6 Next Steps

We are currently defining and developing our Sentient Overlay Network in collaboration with NTT DoCoMo Labs, Japan. We are also in the process of developing collaborations with Intel Labs for the hardware and systems components. We are in discussion with many potential customers for feedback and future trial deployments. We are also synchronized with and contribute to HP's own internal RFID trials and implementations worldwide, giving us opportunities to pilot our developments in real life operational situations and environmental conditions. There is constant two-way communication and exchange of ideas between the HP RFID team and the Sentient Environments team. The first RFID Center of Excellence customer demonstration suite, located in Palo Alto, will showcase our research activities to customers.

6. Service Opportunities

RFID is a new space, yet it embodies many of the attributes of our existing business. While the markets are still developing, we have an opportunity to innovate technologies and business processes. In 1984 Wal-Mart mandated the use of barcodes and in the process transformed the industry. The same company is behind the push for a similar transformation through their adoption of RFID.

The adoption of RFID based supply chain solutions in the short and medium term, and throughout differing business sectors, creates a suite of service areas where HP could offer competitive solutions. Among these offerings opportunities exist for:

Infrastructure Deployment: Installation and testing of RFID readers, sensing infrastructure and IT services within ports, factories and distribution centers.

Data Management Services: Implementation and management of EPC-IS information services for end-product and information sharing between trading partners and multiple execution environments of complex supply chain systems.

Brand Protection Services: Aggregation of RFID data from track-and-trace process. Such services monitor the pedigree of a product, certifying its authenticity and alerting the company to product diversions or shrinkage.

Enterprise Integration: The transformation of a traditional supply-chain into a real-time adaptive supply-chain. To enable this vision, the entire cycle of data capture, data management, analysis and response needs to be integrated into the business processes of the enterprise.

Our present market advantage is due to becoming an early adopter and trial partner with Wal-Mart; we have learnt implementation best practices, which we can pass onto our customers to minimize experimentation at customer sites. However, this advantage may not last very long; we have seen recent announcements from Accenture, IBM and Sun, who are all demonstrating their competencies, either with internal adoption or by reference to customer accounts. The RFID space is likely to become more competitive over time, with eventual commoditization in certain areas. In future, HP's adaptive approach, coupled with our understanding of physically based infrastructure, needs to become a key differentiator as we challenge and transform existing business practices and operations within supply chain industries.

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