Pre-print Manuscript of Article:
Bridgelall, R., "Enabling Mobile Commerce Through Pervasive Communications with Ubiquitous RF Tags," Proc. IEEE Wireless Communications and Networking Conference, New Orleans, LA, Vol 3., pp. 2041-2046, DOI:10.1109/WCNC.2003.1200700, March 20, 2003.

Enabling Mobile Commerce Through Pervasive Communications with Ubiquitous RF Tags

Raj Bridgelall
Symbol Technologies, Inc.,
One Symbol Plaza, Holtsville NY, 11742-1300
rbridge@symbol.com

Abstract - **For many years we've heard of the existence of a wonderful new technology called radio frequency identification (RFID) that allows supermarket items to be checked out without human intervention. Advertisements claim that this technology will be able to locate our keys and spectacles when we lose them around the house - all for pennies. Although technologists amongst us widely recognize this as very early marketing hype, we also admit to having recently witnessed strong evidence that underlying RFID tag performance and cost are fast approaching these initially very optimistic expectations. The future success of mobile commerce or m-commerce will depend on a pervasive communications infrastructure that provides both seamless roaming and automatic object identification. In this paper, we identify key factors that will enable future pervasive deployment of RFID tag and communications technology, thereby leading to the acceleration of applications for m-commerce. For each of these key factors, we provide a summary of the existing impediments and propose potential solutions.**

Keywords – m-commerce; supply chain; RFID

I. Introduction

Major retailers and manufactures have begun to successfully deploy RFID tag technology to enable communications with high-value items that move through the supply chain. End-users are utilizing RFID to track items of significant value, such as pallets and cases, thereby providing substantially improved asset visibility. We have seen strong evidence that RFID tag technology will soon provide the long awaited, cost effective mechanism that will fully automate supply chain logistics [1]. Automation will deliver greatly improved efficiencies and productivity while significantly improving product availability.

End-users plan to deploy larger-scale RFID tag communications infrastructure as initial pilots validate their expected return on investment. Initially, this RFID infrastructure will be separate from a wireless local area network (WLAN) but in time both will become more highly integrated. As the growing demand for RFID tags continue to accelerate their cost reduction, the technology will begin to penetrate the retail point-of-sale. Multi-bit RFID tags have already begun to upgrade the existing single-bit electronic article surveillance (EAS) security tags. Pervasive deployment of wireless infrastructure that provides dual-mode WLAN and RFID tag communications will provide the necessary foundation for even larger scale deployment, and hence more substantial cost reduction. At some point, we expect that the value proposition for tagging individual low cost items will reach an equilibrium state.

The existence of a robust and pervasive dual-mode communications infrastructure for WLAN and RFID tags will trigger numerous opportunities for applications around m-commerce. Consumers will eventually utilize PDA-size multi-technology mobile computers that incorporate both wireless network connectivity and RFID tag communications. Imagine being able to automatically sense and physically locate the exact model of a digital camcorder or TV in a showroom, then view its web-page, evaluate its performance and features, compare prices, and finally place an on-line purchase via the wireless local area network connection.

Section II provides a technology overview and a brief description of the various types of RFID tags currently available and under development. In Section III we describe key factors that our industry must address in order to successfully provide a robust communications infrastructure for m-commerce based upon automatic object identification technologies. Finally in Section IV we summarize the main observations and provide an outlook for the future of m-commerce.

II. Technology Overview

RFID tags are classified into three sub-classes, namely passive, semi-passive, and active. Passive RFID tags do not require batteries for operation and are, therefore, inherently robust, reliable, and low-cost. Their construction is relatively simple. A high performance passive RFID tag consists of a tiny integrated circuit chip, a printed antenna, and an adhesive label substrate for application to items. Active and semi-passive tags require batteries for operation and, therefore, provide greater range and throughput than passive (batteryless) tags. The simple addition of a battery to an RFID tag is a necessary but incomplete feature that classifies it as active [2]. This terminology is often confused when referring to semi-passive tags, which are battery-based RFID tags that do not source electromagnetic energy. We reserve the definition of an active tag to include both a battery and one that also sources rather than reflect or backscatter electromagnetic energy. Therefore, active RFID tags are simply a subset of traditional communication devices such as walkie-talkies, cordless telephones, and personal hand-held data communicators. The major differences are that active tags have fewer input/output (I/O) mechanisms such as synchronization ports, keypads, or displays, and they communicate significantly fewer bits of data over a given time period. For example, active RFID tags may be used to communicate shipping manifests over distances of hundreds of feet only a few times per day. However, personal wireless communicators will transfer orders of magnitude more data per day.

TABLE 1
COMPARING KEY RFID PARAMETERS TO OTHER WIRELESS STANDARDS.

	SRD		WLAN		WWAN	
Parameters	**RF Sensors**	**Bluetooth**	**802.11b**	**802.11a**	**GSM/GPRS**	**IS2000**
Multiple Access	FHSS/ TDMA	FHSS/ TDMA	FDM/ CSMA/CA	FDM/ CSMA/CA	FDMA/ TDMA	CDMA
Frequency Band	125 kHz – 2.5 GHz	2402 - 2484 MHz	2402 - 2484 MHz	5.2 - 5.8 GHz	800 - 2000 MHz	1885 - 2200 MHz
Data Rate	1 - 200 kbps	1 Mbps	1 - 11 Mbps	1 - 54 Mbps	14 - 115 kbps	100 - 2000 Mbps
RF Modulation	ASK, mFSK, mPSK	FSK	DQPSK	nPSK/QAM-n OFDM	GMSK	QPSK (DL) BPSK (UL)
Transmission Power	1 mW - 4 W	1 mW – 100 mW	100 mW	100 mW	2 Watts	600 mW
Typical Range	20' (passive) 400' (active)	30 feet - 100 feet	400 feet	200 feet	20 miles	12 miles

Table 1 provides a brief comparison of the key RFID tag system parameters and how they compare with those of other wireless communication systems with which they must co-exist. We observe that an RFID tag is simply another short-range device (SRD) amongst other popular wireless entities, and may interfere with the operation of other systems sharing nearby channels. This issue will become more pronounced as RFID tag technology becomes pervasive for item identification and tracking.

Equipment manufacturers, end-users, and standards organizations are progressively addressing the traditional barriers to significant RFID deployment. These are no different from the initial barriers to significant deployment of cellular telephony and IEEE 802.11 WLAN networks. We have witnessed a recent acceleration in the performance and cost reduction trends for RFID tags. Commercially available passive RFID systems now operate robustly at a distance of 20-feet, and provide hundreds of tags per second throughput. We expect this range to reach 50-feet within the next two years. Manufacturers have recently demonstrated novel manufacturing processes and convinced us of their ability to soon provide end users with low cost RFID tags [3].

III. FACTORS FOR PERVASIVE DEPLOYMENT

Major retailers and manufacturers have already begun to successfully deploy RFID for tracking goods throughout the supply chain. Many have provided case studies that are readily available on the Internet. RFID sensors are also known as interrogators. They are being incorporated into retail racks and shelves, doorways and portals, thus providing a growing infrastructure for pervasive communications with trillions of physical objects that move around our world. Semi-passive RFID tags also facilitate transport vehicle tracking as they move through tollbooths on the roadway. Therefore, an item's location, model number, expiration date, selling price, manufacturer, and recall status can all be determined in real-time. This capability enables a closed loop control system for automatic pricing, delivery, invoicing, stock level management, and product recall.

Commercially available RFID tags currently operate in the available Industrial, Scientific, and Medical (ISM) frequency bands [4][5]. Table 2 summarizes key considerations for applying one of the currently available RFID tag technologies. We note that RFID tag technologies operating in the high frequency (13.56 MHz) and 900 MHz UHF bands have inherent performance and cost advantages when compared with lower and higher frequency systems.

TABLE 2
APPLICATION CONSIDERATIONS FOR VARIOUS RFID TECHNOLOGIES.

Characteristic	LF (~125 kHz)	HF (~13 MHz)	UHF (~900 MHz)	Microwave (2.45 GHz)
Uniform Allocation	✔	✔	869 & 915	Partial
Protocol Standards	Fragmented	ISO15693	ISO18000	ANSI
Cost (Billions)	> 50¢	< 15¢	< 15¢	< 15¢
Range w/ Mobiles	< 8"	< 8"	> 10 feet	> 2 feet
Data Transfer Rate	10 kbps	30 kbps	256 kbps	256 kbps
Adhesive Labels	✕	✔	✔	✔
Proximity Limitation	Metals	Metals	Liquids	Liquids
Interference	Motors	-	Cell Phones	WLAN

Emerging Market Dominance

Applications for mobile commerce will thrive as RFID technology delivers the following:

1. Robustness of performance.
2. Scalable cost reduction.
3. Uniform multi-level standardization.
4. Secure application middleware and data management services.

We'll further explore each of these as follows:

A. Robustness of Performance

Although we are closer to realizing the robust performance necessary for successful large-scale deployment in the supply chain, numerous problems remain unsolved. Unlike other existing wireless communications systems, the performance of RFID systems is more susceptible to the physical configuration and characteristics of their immediate environment. For example, RFID tags are easily detuned when brought into close proximity with water, metals, and certain types of plastics. That is, materials having a high dielectric constant will form parasitic capacitances with the tuned RF circuits, thereby, diminishing their ability to collect and reflect energy. Nearby RF reflectors will create multi-path nulls that may envelope the tags and prevent energy coupling. The RFID tag sensor networks decode backscatter rather than transmitted energy. Therefore, technology providers must master their understanding of the conditions affecting bi-directional propagation characteristics. Each application will likely have a different environment that will result in large performance variations. Therefore, each installation must be customized.

1) *Operation Near Metals:* Knowledge of the environment and of the RFID antenna characteristics is crucial to the success of RFID systems deployment. If the environment contains many relatively large metal sheets within the antenna's field of view, then a higher frequency tag could be more easily adapted to that environment. Although higher frequency systems typically use dipole antennas for maximum operating range, a patch antenna will provide better performance around metal objects, although at the expense of substantial range reduction.

2) *Operating Near Moisture*: In general, RF propagation systems do not work well near liquids. Hygroscopic materials will significantly distort the near-field pattern as shown in Figure 1, and greatly diminish the amount of energy that can be coupled into the antenna. We illustrate this via the circuit model of Figure 2. The antenna generates a current I_{ant} that passes through a resonant electrical circuit having distributed resistance R_m, inductance L_a, and capacitance C_a.

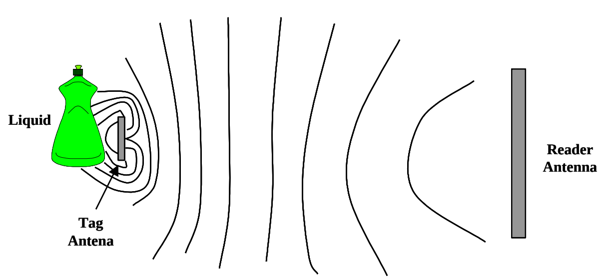

Figure 1: Near-field electromagnetic distortions diminish power coupling.

The impedance matching circuit provides a voltage V_b that is utilized to power the tag. We show that the parasitic capacitance from water proximity adds to the overall capacitance of the power transfer circuit $H'(\omega_o',Q')$, thereby tuning its resonant frequency away from the desired operating point.

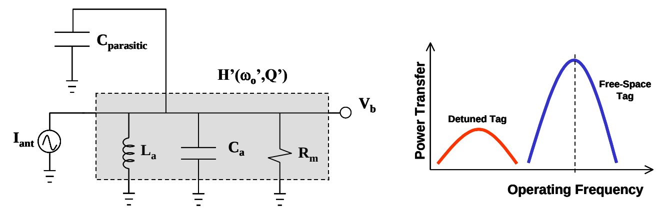

Figure 2: Parasitic capacitances detune the tag's power collection circuitry.

We must reduce this parasitic capacitance if the application requires tagging items with significant water content. This can be achieved by incorporating dielectric spacers that will both physically and electrically increase the coupling distance, which significantly reduces the parasitic coupling capacitance. Each installation site will also have its own specific nuances that may require on-site modifications of the RFID system.

Robust performance will require improvements in the tag design that will yield substantially lower power consumption and detuning sensitivity. This will be accomplished with emerging analog design techniques that provide low-loss, low-voltage rectification without conventional diodes, and wide band antenna impedance matching.

3) *Verifiable Identification*: Unlike reading a magnetic strip card or decoding a barcode, we are not yet able to verify that only one of several *nearby* RFID tags have been read. That is, unlike the laser beam of a barcode scanner, the RF energy cannot be reliably and practically focused onto a specific tag. One of several ideas to address this issue for hand-held reading is to print a barcode onto the RFID label itself, and then link the two identification codes together in the application database. The multi-technology (RFID/barcode) hand-held reader need only decode the barcode and validate it against one of the previously decoded RFID tag's unique identification. This provides the user with a friendly mechanism to first determine the presence of the item before identifying its specific location in a smaller area.

B. Scalable Cost Reduction

RFID tags are still too costly for pervasive infrastructure deployment and full-scale security and identification tag replacement within the retail point-of-sale. Chip size reduction, via *Moore's Law*, will continue to be the dominant cost reduction opportunity while the cost of manufacturing will significantly depend on accelerated demand. Figure 3 shows our expected volume dependent cost projections for RFID tags as the communications infrastructure extends from the warehouse and into the retail environment.

The technology is currently cost effective for tracking high value assets such as pallets and cases. Technology suppliers who demonstrate their ability to reliably scale up production to meet the accelerated demand can lower the price accordingly.

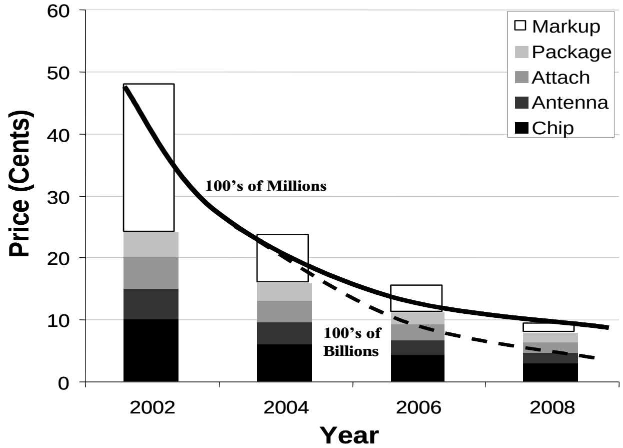

Figure 3: Volume dependent cost projections for RFID tags.

This trend will be similar to that which we are currently experiencing with IEEE 802.11 WLAN technology. As costs decline further, RFID tags will begin to provide an upgrade to EAS functionality within the retail environment. Further deployment within retail will encourage new applications for m-commerce and self-checkout.

C. Uniform Multi-level Standardization

The purpose of RFID standardization is (should be) to:

i. Promote the "peaceful" co-existence of different RFID tag technologies, using either the same or a different frequency allocation, whereby the presence of one technology does not impair the performance of the other.

ii. Ensure interoperability between tags using the same frequency spectrum allocation such that the same device can communicate with any of them.

International standardization facilitates open business processes across the supply chain. Standardization issues are also complex and expansive. They cover protocols and applications; spectrum allocation; health and safety; security and privacy concerns. We expand on each of these as follows:

1) *Protocols and Applications*: As illustrated in Figure 4, many organizations are currently promoting RFID standardization, and this unfortunately results in a highly fragmented process. Each supplier understandably experiences the dilemma of either submitting their technology for global standardization before joining more intense competition, or continuing to protect their intellectual property and risk the challenge of growing only small niche markets.

The International Standardization Organization (ISO) is the most significant international body currently responsible for setting standards around automatic data capture and communications. They represent over 32 countries and have experts from at least 14 member countries directly involved in the development of standards for item identification. The ISO also works with the World Trade Organization (WTO) to eliminate technical barriers to trade by creating worldwide standards. The ratification of any standard, and in particular RFID is a very time consuming and difficult process. Fortunately, end-users are demanding compromises for the sake of driving a single effective standard that can grow the overall market.

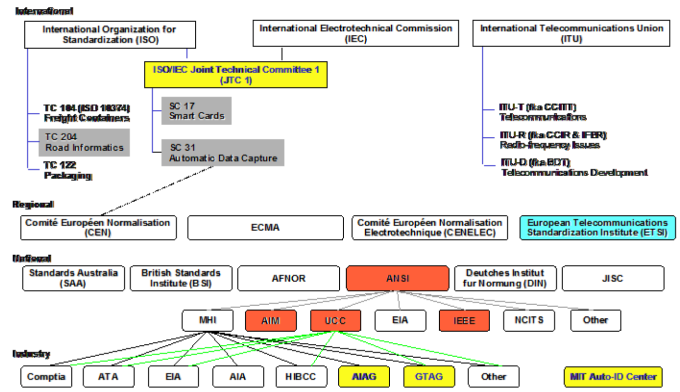

Figure 4: The complexity and fragmentation of RFID standardization activities.

2) *Spectrum Allocation*: Currently, no RFID technology will operate at the same frequency with equal performance everywhere in the world. Low frequency (125 kHz), high frequency (13.56 MHz), and microwave frequency (2.45 GHz) technologies are currently available for RFID throughout the world but at different power levels and bandwidth as summarized in Table 3. UHF technologies can operate at nearby frequencies but with vastly different performance levels. At the time of this writing, some countries, such as Japan are investigating increased power levels for RFID operation in the UHF frequency band [5]. In order to allocate UHF frequencies for RFID, applicants must submit their claims to the International Telecommunication Union (ITU).

TABLE 3
SUMMARY OF CURRENTLY AVAILABLE, WORLDWIDE RFID FREQUENCY ALLOCATIONS.

Frequency	Un-licensed Operation
125 kHz	World-Wide Allocation
13.56 MHz	World-Wide Allocation
458 MHz	Singapore, U.K., Hong Kong (500 mW/45 kHz)
865 MHz to 869 MHz	**Under Development for SRDs in Europe CEPT/ERC/REC 70-03 E** (500 mW/250 kHz now – 2W request for 866.6 MHz under review.)
902 MHz to 928 MHz	North and South America, Taiwan (1 watt spread spectrum)
918 MHz to 926 MHz	Australia, New Zealand, South Africa, China (~1 watt/varying bandwidth)
2.45 GHz	World-Wide Allocation

Varies from 3 mW in Australia to 1 Watt in South Africa.

<u>Under Petition</u> Europe allows 21 dB higher SB than FCC.

2.45 GHz World-Wide	
U.S.	1000 mW
U.K.	100 mW
Belgium	25 mW
Finland	10 mW
France	500 mW
Israel	100 mW
Japan	230 mW
S. Korea	300 mW
Spain	100 mW
Sweden	500 mW
Most EU	500 mW

As next generation cellular telephony (3G) move towards higher frequencies of operation, international regulatory bodies will find it easier to align RFID spectrum in the UHF frequency bands. Technology suppliers currently resolve this issue by designing frequency agile readers. However, this results in unnecessary additional expense, communications latency, and large performance differences. Retailers and manufacturers expect that as countries begin to experience a significant barrier to trade, they will more readily seek to align their RFID frequency allocations.

3) Health and Safety: RFID systems must be installed such that the Maximum Permitted Exposure (MPE) limits are met under all circumstances. Therefore, suppliers must carefully consider the mounting location of antennas, the maximum allowed output power under regulatory constraints, and the antenna's distance from people. Table 4 summarizes the MPE at different frequencies and under various conditions.

TABLE 4
SUMMARY OF NEAR-FIELD EMISSION SAFETY STANDARDS.

2.4 GHz			
Nation/Region	**Standard/ Requirement**	**Allowed Power Density**	**Averaging Period**
U.S.A.	FCC Title 47 CFR Part 15, R&O 96-326	10 W/m^2	30 minutes
Europe	CENELEC ENV 50166-2	10 W/m^2	> 6 minutes
Japan	RCR STD-38	10 W/m^2	6 minutes

FCC					
MPE @ 20 cm	125 KHz	13.56 MHz	458 MHz	915 MHz	
	1 W/m^2	9.8 W/m^2	3 W/m^2	6.1 W/m^2	30 min Window

	Whole Body	Partial Body	Hands, Wrist, Feet, Ankles
SAR	0.08 W/kg	1.6 W/kg	4 W/kg
Avg Over	Whole Body	1 g (cubic chunk)	10 g (cubic chunk)

Consumer groups have already begun to query technology suppliers about the health and safety compliance of systems that communicate with RFID tags in their environment. In 1995 the European Telecommunications Standardization Institute (ETSI) sub-committee, European Committee for Electro Technical Standardization (CENELEC) published the pre-standard ENV50166-2 advising that when the antenna is within eight inches of the body, uncontrolled emissions should not exceed 10 watts per square meter when averaged over any six-minute interval. The Federal Communications Commission (FCC) also follows these recommendations for North America, based on inputs from American National Standards Institute (ANSI) and the Institute for Electrical and Electronic Engineers (IEEE).

4) *Security and Privacy*: Consumer privacy groups have already engaged RFID tag manufacturers regarding their concerns about being tracked via the RFID tagged items that they are carrying. Unless retailers automatically destroy the tag at the point-of-sale, the consumer will be able to further utilize their functionality for identification applications such as in the home. For example, the dream of automatic item replenishment systems for the home will be closer to reality as the cost of RFID tag sensor networks approach those of cordless telephones. Some consumers are already using RFID in the home to monitor the dispensing of medication. While RFID can continue to provide a useful function in the home, they can also become the instrument of privacy invasion. Retailers and manufacturers would like to maintain the RFID functionality after the item is purchased to more effectively manage the expensive return and recall processes. However, they must weigh this benefit against the privacy concerns of the consumer.

One possible approach is to disable all tags at the point of purchase by default. The consumer should have the option to retain the RFID functionality based on some loyalty program that will also facilitate return and recall procedures. For example, if their loyalty card is scanned, the system will disable the EAS but not the RFID function. Consumer product manufacturers must also be responsible for educating the public about the technology and its potential benefits. This will help to create a more positive attitude towards the future of mobile commerce with automatic item tracking.

D. *Systems Integration*

As RFID tag technology becomes ubiquitous and their communications infrastructure pervasively deployed, their need to co-existence with other wireless technologies will become even more pronounced. The flow of data from tags everywhere will potentially overwhelm any centralized data management system and so the need for a standard distributed object database will become more evident.

1) *Technology Co-existence*: RFID tag communications infrastructure will co-exist with other forms of wireless communications technologies that have overlapping and complementary performance specifications as illustrated in Figure 5.

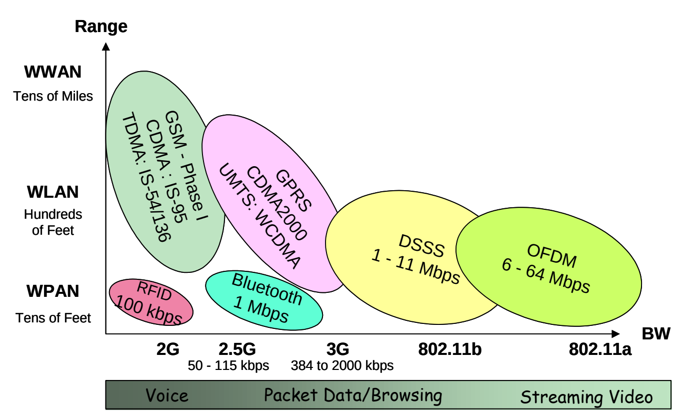

Figure 5: RFID must co-exist with other wireless technologies.

Their operating frequencies often overlap and their modulation schemes are similar. For example, some emerging semi-passive RFID systems will utilize frequency hopping spread spectrum in the microwave ISM bands, thereby competing with Bluetooth systems for channel access. Technology suppliers will have an opportunity to combine many of these technologies in a synergistic manner that will yield greater degrees of coordination and seamless mobility. For example, we are aware of technological developments that will combine RFID, WLAN, Bluetooth, and even micro-cellular wireless wide area network (WWAN) base stations into access points [2]. This is a necessary step towards providing cost reduction and enhanced quality of service.

2) *Seamless Data Communications*: Pervasive RFID systems deployment will result in data generation that significantly exceeds that of existing wireless data communications technologies. Trillions of tags will communicate with a wireless network of distributed RF sensors. Therefore, a data management infrastructure must be in place to coordinate the transition of data between different networks that are using different standards.

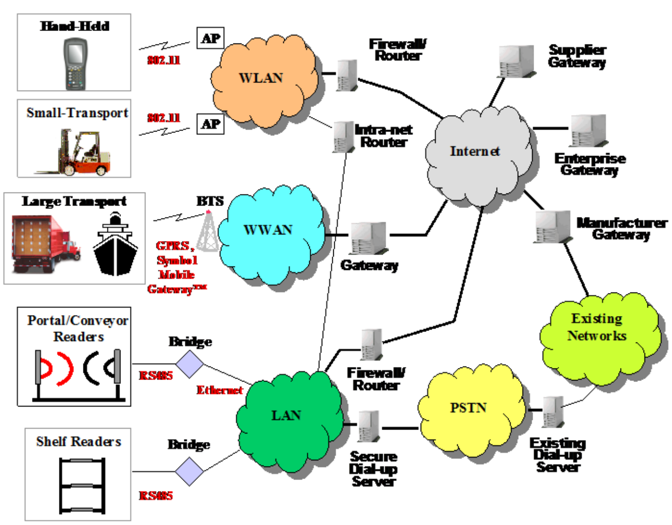

Figure 6: Local and enterprise network interfaces for global data management.

Mobile computers that roam between networks must do so seamlessly without losing their connection during an m-commerce based transaction. Figure 6 provides an example of a scalable architecture for pervasive deployment of RFID tag communications.

Retailers have begun to pilot applications that utilize hand-held mobile computers with RFID tag readers and WLAN connectivity in the retail environments. They have also installed shelf readers and portals that are connected to a wired LAN. Even large transport containers carry tags that communicate their location and shipping manifests over the WWAN. We need a flexible, standard, and scalable wireless communications infrastructure that will facilitate secure data management and communications.

IV. Conclusions

In this paper we introduced an often-ignored technology that promises to revolutionize mobile commerce through the deployment of a pervasive communications infrastructure for tracking and identifying physical objects. RFID tag technology requires a communications and data management infrastructure that must co-exist with other wireless communications technologies. Retailers are deploying this fast emerging technology in stages that begun at the warehouses of the retail supply chain where IEEE 802.11 WLAN systems are very successful. Retailers have already begun to extend RFID tag sensors and mobile data capture devices with WLAN connectivity into the retail environments. They are also upgrading existing electronic article surveillance security devices with RFID tags. As the manufacturing volume increases and cost declines further, RFID tag systems will finally move into the homes. At this point the technology will be pervasively deployed and applications for mobile commerce will thrive. We identified the major factors that will be responsible for realizing this viewpoint. Within each factor, we addressed their specific challenges for enabling mobile commerce around a wireless multi-technology (WLAN and RFID tag) communications infrastructure that provides seamless mobility and automatic object identification. These are the necessary ingredients for enabling mobile commerce through pervasive communications with ubiquitous RFID tags.

References

[1] Bridgelall, R., "UHF Tags – the answer to the retail supply chain prayers?," RF Innovations Magazine, August 1999.

[2] Bridgelall, R., "Bluetooth/802.11 Protocol Adaptation for RFID Tags," Proceedings of the 4th European Wireless Conference, Florence, Italy, February 28th, 2002.

[3] MIT Auto-ID Center Publications at http://www.autoidcenter.org/

[4] US Code of Federal Regulations (CFR), Title 47, Chapter I, Part 15.

[5] ETSI EN 300 220-1 V1.3.1, September 2000.

[6] RCR STD-33A, Japan Research and Development Center for Radio Systems, March 1993.