Globalization Demands Innovation in Standards Agnostic Systems Interoperability

Potential ROI from RFID by improving global transparency through UWB & UWB+NB with SDR as an LPS solution

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Background

Nature's gift of the radio spectrum is subjected by humans in government and industry to dissection and control. It has resulted in a globally fractured state of communication when using radio frequency. Redundant investments are necessary to move between "restricted" frequencies and the process has turned into a sham with spectrum auctions pioneered by several affluent nations for commercial purposes. Regulating the use of radio spectrum has distinct advantages (defense, emergency, medicine) but the current quagmire may overshadow the benefits.

During WWII, the discovery of RADAR unleashed the potential to use of radio frequency to identify objects. Almost half century later, in 1987, Norway pioneered the first public use of radio frequency identification (RFID) in the form of RFID tags attached to automobiles that could drive through toll collection points fitted with readers. The event triggered automated toll collection through a pre-agreed financial transaction. The RFID tag operated at a fixed frequency and the frequency used was (and is) irrelevant to the function of the static id system. But, globalization has stimulated movement of objects across diverse geographies. Now it is imperative that we focus special attention to determine the state of supply and demand of goods. Calls for global visibility of goods movement require automatic identification of the vast number of objects (in trillions) moving around the globe. This necessity may be answered in part by harnessing the internet to catalyse the re-birth of the use of RFID. Thus internet-based object identification was re-born at the hands of the Auto ID Center at MIT beginning around 1999.

Opportunity

The surge in the popularity of RFID bypassed the fact that RFID tags operate in a fixed frequency. In other words, tag readers must also operate in the same fixed frequencies, to be useful. Add to this the different spectrum usage specific to geographies plus the preferences for standards for data capture and air interface. What emerges is an interoperability nightmare from multitude of tags, readers, investment in multiple infrastructures and complexity of multiple "standards" that may co-exist in a plethora of proprietary systems used by global systems.

Potential to Eliminate Frequency Heterogeneity

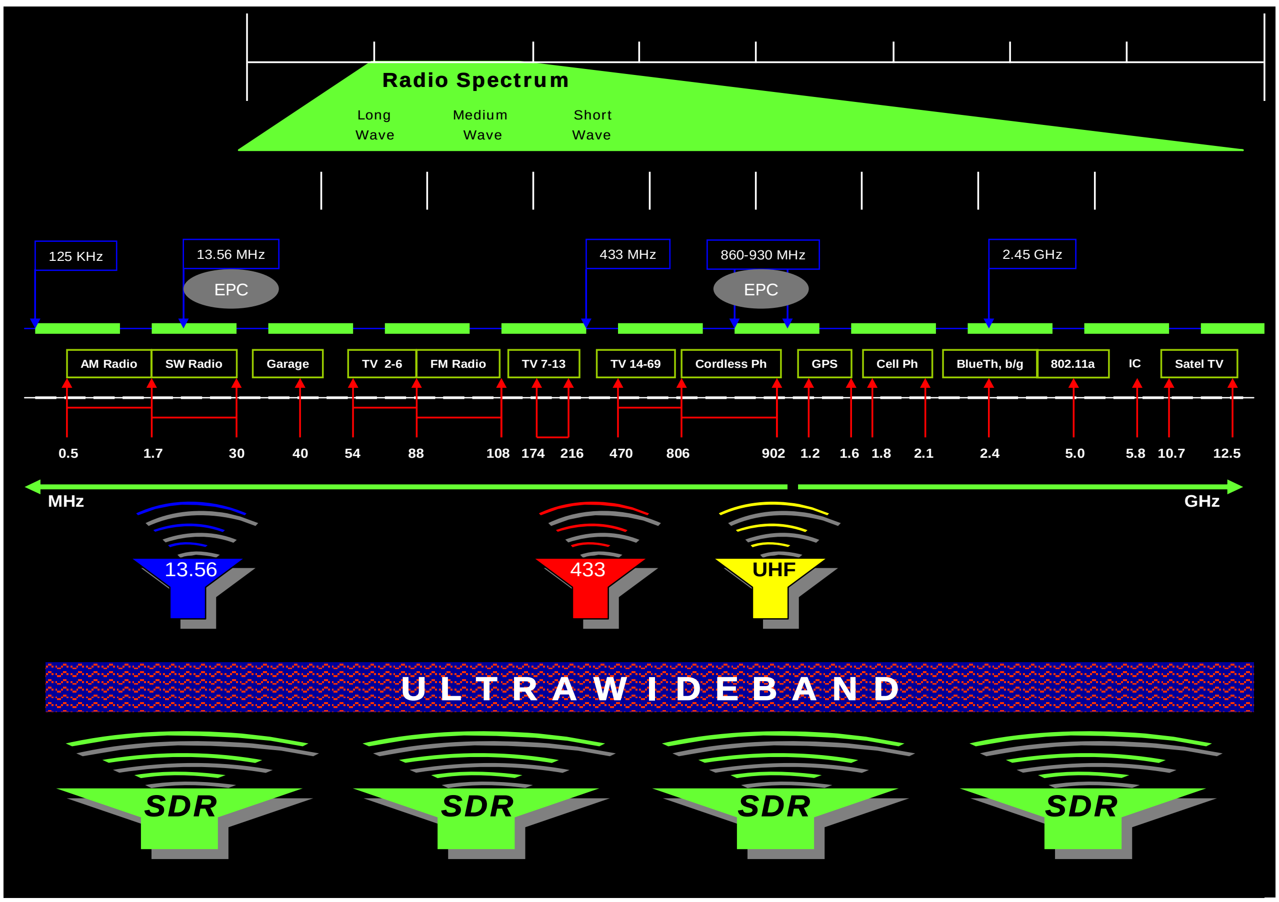
The problems with automatic identification should not suggest that automatic identification has lost its appeal. Auto id and concomitant location of object are important data elements whose value is growing exponentially in business supply chains and even more critical for security of global trade for example in multi-national logistics operations such as goods transport between Asia and Europe on the Trans-Siberian Railroad. In such systems, fixed frequency RFID tools may be a hindrance to operations and are liable to create gaps in (data) transparency due to lack of systems interoperability. This article highlights technologies that may eliminate frequency heterogeneity for some applications. It is neither a total solution nor a panacea that calls for discontinuing use of fixed frequency systems.

Frequency Agnostic Technologies: Ultrawideband (UWB) and Software Defined Radio (SDR)

In use since 1962, UWB [1] is essentially RFID but it can communicate over a broad (hence, ultra wide) spectrum (band) rather than fixed ranges that are common in typical RFID. The physics of transmission is different and enables UWB to use short (pico second) bursts of frequency over the broad spectrum (hence, difficult to de-code). This is a frequency agnostic tag that is currently used in several operations as an active tag (battery) but holds the potential to be transformed into a passive format.

Invented [2] in 1991, SDR is essentially a radio that can operate (receive and transmit) over a broad spectrum (think, car radio). Hence, it can interrogate tags and receive signals from UWB tags. The incoming frequency is selected using the software embedded in these devices (hence, software defined radio) hence it is immune to frequency heterogeneity and functions in a manner that is frequency agnostic.

Combination of frequency agnostic UWB tags and SDR readers may reduce geographic barriers to auto-id adoption.



[1] http://www.uwbforum.org/; http://www.intel.com/technology/comms/uwb

[2] Bose, V. G. (1999) Design and Implementation of Software Radios Using a General Purpose Processor. PhD thesis, MIT. http://www.findarticles.com/p/articles/mi_m0EIN/is_2005_Nov_29/ai_n15881921; http://www.sdrforum.org http://www.wipro.com/webpages/insights/softwareradio.htm

Standards are not a standard solution

Track and trace technologies are swimming in a multiplicity of so-called standards. Problems encountered due to globalisation result from the unlimited movement of objects (inanimate and animate objects such as humans) in domains where the standards are not useful, practised, accepted, adopted, implemented or enforced. Systems between domains severely lack communication skills due to lack of interoperability. We have an embarrassment of riches with respect to data while we continue in abject poverty of information due to lack of interoperability in this systems age. The latter has, erroneously, promoted even more calls for standards and even larger consortiums are being formed to muscle global adoption (acceptance). The success of this approach is open to question by the failure of Wal*Mart-esque efforts to usher in global visibility that aut id was touted to deliver.

The lesson from the age of introduction of the electric dynamo is ignored by the current drive to pursue that holy grail of one standard or the lowest common denominator. It is clear that global leverage should be used to promote interoperability between select partially adopted standards in a way that foreign systems can interface seamlessly with another through translational mechanisms (that are so obvious from human language). It is this theme that I term as being standards agnostic yet standards compliant. The example in this note draws from the recent hype of RFID but aims to emphasize that technology is a tool to add value to a process or enable *decisionable information*.

Ultrawideband (UWB)

Most RFID types (125KHz, 13.56MHz, 433MHz, 915MHz) possess a spatial capacity of 1 kbpspm^2 (IEEE). Spatial capacity focuses not only on bit rates for data transfer but on bit rates available in confined spaces (grocery stores) defined by short transmission ranges. Measured in bits per second per square meter, spatial capacity is a gauge of "data intensity" that is analogous to lumens per square meter that determines the illumination intensity of a light source. Growing demand for greater wireless data capacity and crowding of regulated radio frequency (approved ISM spectra) will increasingly favour systems (spectrum) that offers appreciable bit rates and will function despite noise, multipath interference and corruption when concentrated in smaller physical areas (stores, warehouses). Will spatial capacity limitations clog the ‘interrogation’ system when item level tagging becomes a reality? Some are exploring BlueTooth with spatial capacity of 30 kbpspm^2 while asset management may use 802.11a protocol (5.15-5.35 GHz) with spatial capacity of 55 kbpspm^2 (for example, metal spare parts in an air force base).

Quite a few companies are exploring ultra wideband since its appearance on the scene in 1962. UWB spans several gigahertz of spectrum at very low power levels below the noise floor of existing signaling environment. The spatial capacity of UWB is 1000 kbpspm^2 or 1000-fold more than 802.11b. Conventional narrow band technology (802.11b, BlueTooth, 802.11a) rely on a base "carrier" wave that is modulated to embody a coded bit stream. Carrier waves are modified to incorporate digital data through amplitude, frequency or phase modulation. These mechanisms are, therefore, susceptible to interference and the coded bit stream (for example, electronic product code or EPC) could be decoded or intercepted, posing data security issues. UWB wireless technology uses no underlying carrier wave but modulate individual pulses either as bipolar or amplitude or pulse-position modulation (sends identical pulses but alters transmission timing). UWB offers pulse time of 300 picoseconds and covers a broad bandwidth extending to several gigahertz. UWB operates in picosecond bursts, hence, power requirements are drastically lower (200 mW) compared to 802.11b (500 mW) or 802.11a (2000 mW). The data rate for UWB (0.1 – 1.0 gbps^2) is staggering when compared to 802.11b (0.006 gbps^2). Sony and Intel, among others, are leading this research for wireless transmission of data, video, networked games, toys and appliances. Today we have robotic vacuum cleaners and lawn mowers that clean the living room or the manicured garden without ever touching the sofa or grazing by the rose bush. Universal appeal for UWB is latent in its capability to offer a global standard. Without FCC-like country-specific restrictions, an old technology like UWB still remains virgin for many possible applications and may be the only global wireless communication medium that may claim, someday, a truly global standard.

After September 11, UWB transmitters (like RFID readers) were mounted on robots for search missions at the World Trade Center since UWB is less hindered by metal (Coke cans or turbine spare parts) or concrete (buildings and warehouses). On 14 Feb 2002, the FCC gave qualified approval to use UWB (see www.fcc.gov/e-file/ecfs.html) in the range >960 MHz, 3.1-10.6 GHz and 22-29 GHz. Limiting power also limits UWB efficacy and spectrum.

UWB-RFID active transponders are not prohibitive (cost) while transmitters are cheaper than 802.11b RFID readers because they do not need many analog components to fix, send and receive specific frequencies. The combination of UWB plus narrowband technology to produce a passive UWB transponder may be a reality (by combining UWB communication with narrowband RFID tag). Combining a narrowband receiver and a wideband transmitter in the tag optimizes collecting RF energy on the receive channel combined with ultra low power on transmit channel. At the MAC layer, optimized conflict resolution algorithms allow multiple tags to communicate efficiently and effectively with the reader. Due this algorithm the channel is used very efficiently (OFDM), resulting in an increased effective bandwidth that allows more tags to communicate with the reader. Similar use of OFDM to enhance fixed frequency RFID readers is not known, to the best of my knowledge. Thus, utilization of narrow band downlink and wide band uplink communication enables wholly (passive) or partially battery-less tag designs to be manufactured at low cost. UWB communication is resilient to selective RF absorption, since the data can be recovered by the reader by relying on the message content in the 'not-absorbed' frequency bands. Due to the very broad frequency content of the transmitted UWB impulse, it is extremely resilient to path fading and enable readers to determine location of tags. Thus, not only can UWB tags identify but it can also locate (for example, movement of objects in a warehouse as well as the storage organization). Unlike traditional passive RFID tags, passive UWB tags use the accumulated power to transmit UWB impulses to the reader. Tags are re-writeable and can be programmed to have 64, 96, or 128 bits (EPC, GTIN and IPv6 scheme discussed in http://esd.mit.edu/WPS/2007/esd-wp-2007-17.pdf).

Despite the clear advantages of passive UWB RFID tags, in general, the dispute in the field stems from claims that UWB transmission may interfere with spectrum used by cell phones and air traffic control. FCC is investigating but it is poised to open up even more of spectrum for UWB commercial applications. Without the burden of license fees for spectrum usage, the commercial floodgates for UWB usage may be unstoppable much to the chagrin of the telecom industry. MSSI is charting new territories and PulseLink has shown that SDR readers work with UWB chips.

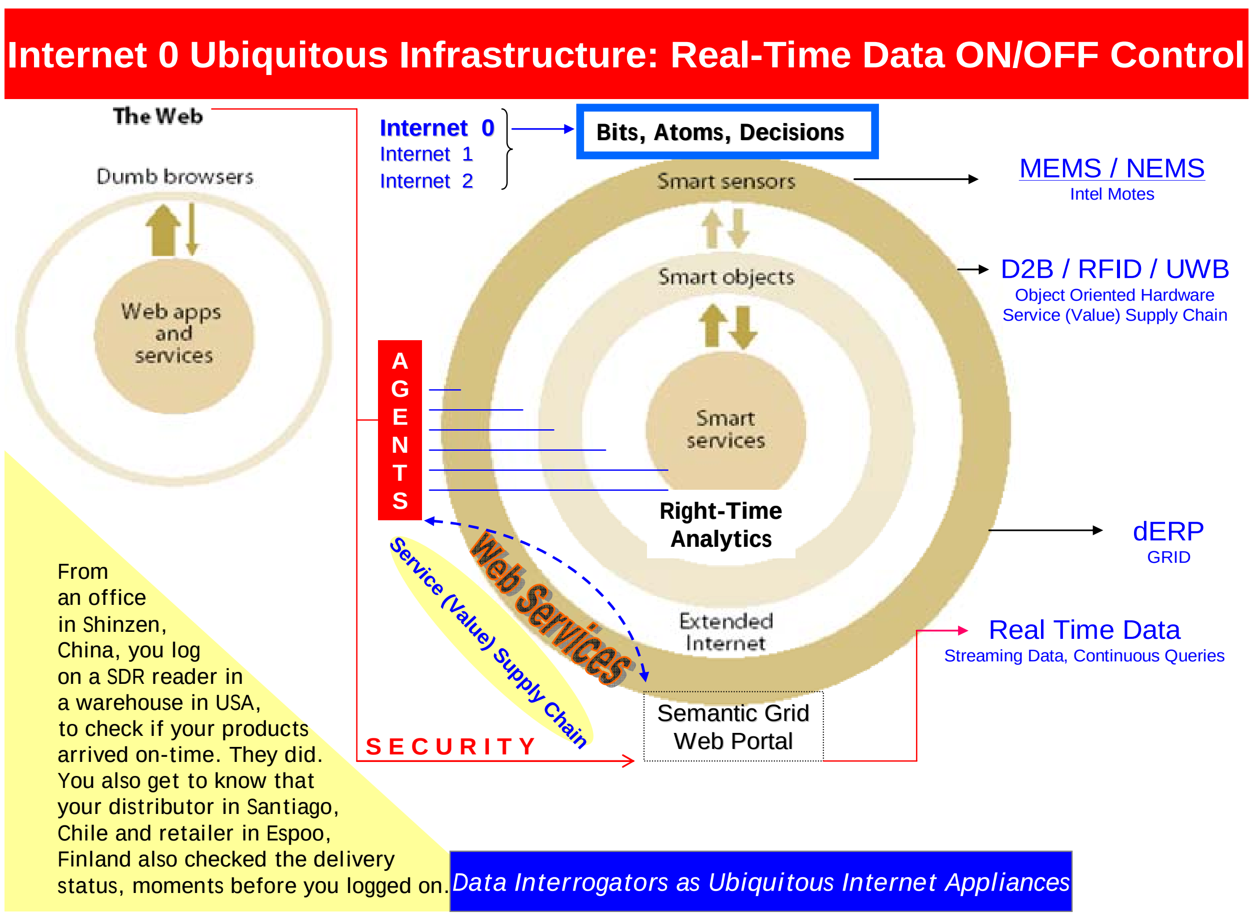
Software Defined Radio (SDR)

The current thinking to use 'readers' specific to one or more RF modes may not be a sustainable approach for the infrastructure necessary for object identification to become pervasive. In 2004, heterodyne readers that can read MHF (13.56MHz) & UHF (902-956MHz) tags cost about $5000 (ThingMagic). Consider commonly used frequencies, RFID vs UWB, passive vs active, many standards (EPC, GTAG) and regional regulations (RF spectrum, emitted radiated power). Taken in combination, it spawns several types of transponders and to read the tags we will need a variety of readers. Multi-frequency tags will not stem the problem. Current readers cannot read UWB tags. Hence, according to the current model, businesses dealing with objects from global partners, therefore, must possess infrastructure (several types of readers) compatible to read a plethora of tags. Current reader vendors, inflate the hype and exhibit lack of foresight, thus, delivering a debilitating blow to the real benefits of object identification and sharing of data to improve processes such as business operations, healthcare and military readiness.

Readers must be ubiquitous as a *civil engineering infrastructure* similar to electrical outlets, evolving to form the internet of devices (Interdev) with software as a part of the infrastructure to enable pervasive data acquisition. Data sharing may be a reality if security enabled open source software may be a part of the infrastructure. Control, security, updates and hardware improvements are delivered via this ubiquitous systemic software infrastructure.

It is this scenario that is outlined in the illustration (below) where the reader in the warehouse is always 'on' but the ability to read certain objects (or not) is controlled through the software layer by the authorized user and the authorizations allowed by the principal user. The 'views' of the contents of the warehouse is limited to goods that the user can 'read' by virtue of the preamble that must be exchanged and validated between the reader and tag (similar to current architecture that is embedded in EPC specifications and can be adopted elsewhere).

Software defined radio (SDR) is probably the simplest solution at hand to deliver this ubiquitous infrastructure in a manner that will remain transponder hardware agnostic with all modulations effected through the SDR OS. This view, that of, using SDR hardware (in some form) as ubiquitous RFID interrogators (in your refrigerator or in a warehouse) is the proposal based on the current understanding of SWR (software radio) and confirmation from its inventor (Vanu Bose, Vanu Inc). In 1991, the term "software defined radio" was coined to describe radio devices implemented in software and running on generic hardware. Because SDR is linked to global mobile telephony, an area of convergence between SWR infrastructure for real-time data and *delivery of real-time data as a service*, may evolve as a robust business for telecom providers. In 2002, a service model was explored by NTT (www.ntt-east.co.jp/tmmall/rf.html) and a revenue model is discussed in http://esd.mit.edu/WPS/2007/esd-wp-2007-17.pdf



Software Defined Radio - SDR (from Vanu Inc)

Reconfigurable SDR is a category of software radio that has been built for defense applications over the last decade, typically involving a combination of processing technologies such as application-specific integrated circuits (ASIC), field progammable gate arrays (FPGA) and digital signal processors (DSP). Despite good performance of current systems, software investment for such systems are high and they soon become obsolete as technology accelerates. One example is the SpeakEasy system. It was built around a combination of FPGAs and 40 MHz TI C40 DSPs. By the time the first prototype was demonstrated, COTS DSPs were available at 166 MHz. As the SpeakEasy software was tied not only to the C40, but also to a specific layout of C40s and FPGAs, the new DSPs could not be exploited.

The most advanced type of SDR, Software Radio (SWR), maximizes software reuse across platforms and hardware generations. SWR implements the signal processing software as an application-level program running on top of a standard operating system (OS) (whether on general purpose (GP), central processing units (CPUs), DSP or other processing engines), giving it the flexibility lacking in other SDR types. The use of application-level software and an OS both reduces software development costs and allows the underlying hardware components to be upgraded without incurring the high cost of redeveloping the software. As a result, SWR systems can track the Moore's Law performance curve over time at a much lower cost than other types of SDRs. As SDR technology progresses, the flexibility and performance of SWR will give it a clear advantage over not only traditional radio architecture, but also other SDR types. Its unique ability to add features through software upgrades and to enable a single radio to support multiple standards has drawn interest to this technology from many markets, from cellular providers to public safety agencies.

Hardware architecture

The architecture of a software defined radio can be divided into three distinct elements: a digital signal processing section, a section responsible for the conversion between RF and digital and the antenna. While the performance of the antenna and RF to digital conversion play a key part in determining the capabilities of an SDR platform, the flexible digital signal processing is what qualifies it as a software defined radio. FPGAs, DSPs and GP processors are the three leading technologies that can provide the flexibility and processing power needed for SDR systems.

The hardware architecture groups the hardware components into three blocks representing the antenna, RF-to-digital and processing subsystems. No hardware component in the architecture is specialized to any particular waveform. While the architecture places no limitation on the achievable waveforms, any given implementation of the architecture can only support some waveforms. Each implementation supports a limited range of RF frequencies, bandwidths and amount of computational power. For example, in order for a platform to be software upgradeable from 2G to 3G cellular standards, the implementation must be able to receive a 5 MHz wide band in the appropriate frequency ranges and have enough computational power to perform the 3G processing.

The interfaces to the antenna block are RF transmit and receive analog lines and a digital control interface. With these interfaces, the architecture can accommodate traditional passive antennas (digital interface has no function) and advanced systems (electrically controllable antenna arrays). The architecture does not specify a particular type of digital connection (eg: RS-232), as this is a detail of the implementation. RF-to-digital, is the only layer of the system that contains radio-specific analog components. On the receive side, its sole function is to generate a digitized representation of a down-converted slice of the radio spectrum. On the transmit side, it generates an up-converted radio signal from a digitized representation. This block does not perform waveform specific processing such as demodulation or equalization. The third block, motherboard, is borrowed from the PC because software radios look much more like computers than like legacy radios. Like a PC, this layer contains memory and processor components and provides I/O to a network, to the user, timing support and similar functions.

Applications

SDR technology can be used in any device that uses RF for communication, which encompasses a wide range of products including cellular base stations, military communications systems and public safety radios.

Technology in cellular base stations

Cellular standards evolve slowly, from analog in the 1980s to digital in the 1990s and possibly to 3G sometime this decade. While the underlying processing, communications and DSP technology evolves rapidly, cellular service is limited to once-a-decade upgrades because the high capital costs of infrastructure upgrades are prohibitive. For example, AT&T and Cingular are upgrading their networks from time-division multiple access to (TDMA) to the global system for mobile communications (GSM). This “upgrade” actually involves building out a new GSM network in parallel to their existing TDMA network, an initiative that costs each carrier upwards of $4 billion and requires a 10-year deployment to achieve a reasonable return on investment.

A wireless network infrastructure using software radio technology can be software upgraded to new standards, thus deploying new standards more quickly and at lower cost than today's approach. Carriers can then increase revenue by rapidly implementing new revenue generating services as well as new systems that use spectrum more efficiently. A further benefit of SDR is reduced operating expenses — many of the maintenance and upgrades today that require truck convoys to tower sites could be serviced as remote software changes in an SDR system. The architecture for a SDR base station is essentially a basic SDR with an array of processing elements that can be scaled to handle more capacity or more complex waveforms. Using current x86 general purpose processors as an example, it is now possible to provide one GSM channel with 8 time slots for every 1 GHz of processing. Standard networking equipment such as gigabit Ethernet now has the bandwidth to supply digitized spectrum and allows the use of standard PC servers with x86 processors to act as the cluster of processing units. The radio section of a software radio base station is responsible for converting a wide band of radio spectrum to a digital IF. This equipment is available today in the form of multi-carrier power amplifiers, wide-band up-converters and down-converters and high-speed A/D and D/A converters. This provides a digital interface that is completely independent of the air standard and able to support multiple channels of different standards in a band. When coupled with a SDR backend, it is possible to change air standards simply through a software upgrade.

SDR eases standards woes

SDR can also mitigate problems carriers face when switching to a new standard. Generally, capacity is moved to the new standard slowly, so that customers are not forced to immediately upgrade their phones. Limited spectrum availability means the carrier must decide at some point to take away capacity from the old standard in order to add capacity to the new standard. A SDR base station can run two different air standards simultaneously, operating a control channel for each standard and saving an operator from having to make this decision at each tower. Additional capacity then can be added to each standard on an as-needed basis, changing the number of channels used by each standard dynamically, depending on the number of users requiring voice channels for each standard.

Base station hotelling is a new architecture for deploying cellular systems that takes advantage of SDR's flexibility to lower capital costs and make more efficient use of the spectrum. Companies are now separating the base station from the antennas in order to improve coverage in urban areas and add coverage to tunnels, stadiums and within buildings by putting the antennas where they are most needed. These remote antennas provide the RF spectrum over a fiber optic cable back to a central location where all of the base station processing resides. This method also better utilizes base station resources, as channels can be allocated to different locations to match the load as it varies over the course of a day. For example, at rush hour, more resources can be applied to towers on the highway, whereas these same processing resources could be allocated to the downtown office area at other times of the day. It is no longer necessary to outfit towers with capacity for the peak load — capacity that will sit idle during off-peak hours. Adding capacity to the entire system is now as easy as adding a server to a rack in the central location, eliminating a trip to the tower. Additionally, the benefits of a SDR base station still apply. It is possible to run multiple standards simultaneously from a single hotel site using the same hardware, even supporting multiple wireless services providers from the same infrastructure base. This ability to share infrastructure between standards or carriers greatly reduces capital costs for the providers.

Military

Interoperability problems are also an obstacle in joint operations, where each nation typically has its own radio systems. Recently, emphasis on peacekeeping, disaster relief, homeland security and other non-combat military operations has created further problems. In these roles, military units must communicate with public safety agencies, humanitarian organizations and civilians. Single SDR with the ability to support multiple waveforms significantly reduces the number of devices needed in the field. For military users, who must maintain, transport, power and manage each device under challenging conditions, the benefit of a streamlined system is substantial. SDR promises to reduce military radio development and acquisition costs. Without SDR, new device development requires investing anew in the implementation of each supported communication standard. With SDR, the bulk of the implementation knowledge for a communication standard is captured in portable software, which can then be reused at low cost in new or different platforms. This software reuse holds the potential to revolutionize radio procurement by significantly increasing competition among platform vendors, leading to reduced per-unit costs.

US DOD recognizes the potential cost reduction of SDR and has established the Joint Tactical Radio System Joint Program Office (JTRS JPO) to achieve that goal. The JPO has begun to acquire software implementations of a first set of 33 communication standards. The linchpin of the JTRS effort is a standard - the software communications architecture (SCA) - intended to ensure portability of the implementations across platforms from many vendors. SCA standardizes the software's operating environment and the control and communication mechanisms for both the hardware and the external interfaces of the radio. Many NATO allies have signed agreements to apply the SCA in their future acquisitions. JPO expects SCA to become the basis for commercial SDR software standards as well. The Federal Emergency Management Agency has identified radio interoperability as the one item that could have made the most significant difference in the rescue and cleanup effort after the 9/11 disaster. The unplanned nature of an emergency requires extremely flexible radio systems that are able to adapt to the situation and diverse communications needs, making SDR the ideal technology for public safety radio systems.

Need for the 'next-generation' infrastructure thinking and leading the change

RFID usage is at a critical point in its technological evolution to fully realize the benefits of real-time supply chain and inventory management or to be the technology of the choice for security applications. The challenges are:

- Current RFID technology, theoretically, can process a maximum of 80 tags per second. The actual numbers of tags that can communicate with the readers are much less. The limitation is in the back-scattering method that the tags use to communicate with the readers and the number of packet collision (that increases nulls) reduces the packet rate significantly.

- RFID tags cannot be simply placed on liquid or metal containers, because of RF absorption and reflection by those materials.

- Tags only can transmit their ID but many services also require location information that cannot be provided location since the communication is based only on narrowband RF.

- Readers respond to fixed frequencies using analog components and multi-frequency readers are far too expensive due to 'doubling' of components. It is unsuitable for large scale adoption.

- Absence of hardware/software infrastructure as an ubiquitous data infrastructure for intelligent information

Implementation Example of Active UWB

This document sketches the use of active UWB in asset management with respect to IT architecture, physical plan and system cost. Reader locations are based on a 3PL warehouse for pharmaceutical goods. Figure 1 illustrates the warehouse (630' x 210' x 30'). Warehouse include 2 docking gates leading to 1 receiving area, 5 metal shelves (h= 18 feet), several fenced areas, open areas used for storage, an administration building and a yard (630' x 300').

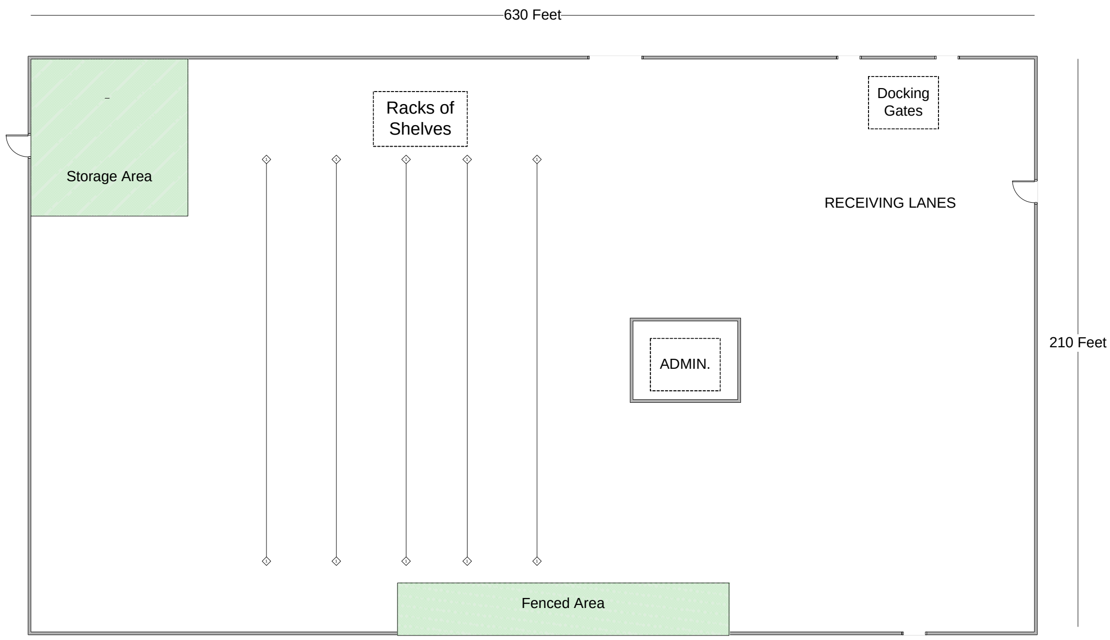


Figure 1: Warehouse

Technological Requirements (to meet operational needs)

(1) Visibility of physical space such that each object can connect (receive / transmit) with at least one reader (no communication black holes). In case of a blockage of direct path from a specific tag to a reader, the tags should be able to use the relay capability of neighboring tags.

(2) Data read-write and exchange with ERP.

(3) Location accuracy of 1-2 feet (>95%). Precision of location requires triangulation by readers.

(4) Range (tag to reader) is approximately 300 feet (indoor) and 1500 feet (outdoor).

(5) Enough redundancy to prevent system failure due to failure of any one component.

(6) System efficiency >99.8%.

The Proposed Solution > **Software Structure**

The top layer is composed of an ERP system or legacy system with different operational modules: HR, MRP, TMS, SCE, WMS, etc. The active UWB system is integrated with the operational modules through a middleware layer (part of ERP or external product) that receives the data from the layer below (communication layer) and transfers it to the layer above (application layer). The communication layer issues commands to hardware (tags and reader), for example, to locate objects.

The Proposed Solution > **Physical implementation** (inside the warehouse)

Multiple readers (located in the physical space under discussion) and tags are attached to objects that are located in the same space. The goal is to optimize the RF coverage of the physical environment in which the system is operated to maximize reliability of communication.

Omni coverage or directional coverage (use directional antenna) for fixed readers. Portable readers also included. Based on statistical propagation models for various in-door spaces (and their multi-path characteristics), the tag to reader coverage is 100 m (min 30–40 m). Each object is covered by at least 2 readers for precision of location. Total number of fixed readers in the warehouse turns out to be between 13 to 15. The installation includes LAN cables which run between all the readers and server or readers may communicate with the server via WLAN. In order to convert (X, Y) location data into actual physical space (rack /shelf / bin) a calibration exercise is necessary. For Z coordinate, coverage of three readers per tagged object is required (hence increases infrastructure cost).

Figure 2: Semi generic reader layout for warehouse: 8 omni-directional readers (hung from ceiling) and 7 directional readers (on walls).

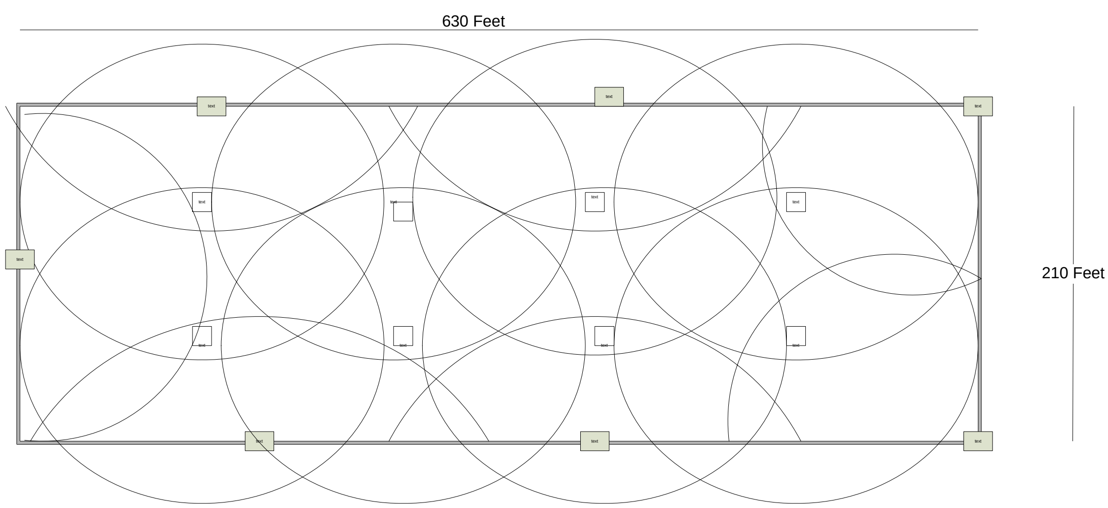


Figure 3: Tailored reader layout: 4 ‘omni’ and 9 directional readers (more coverage for shelves)

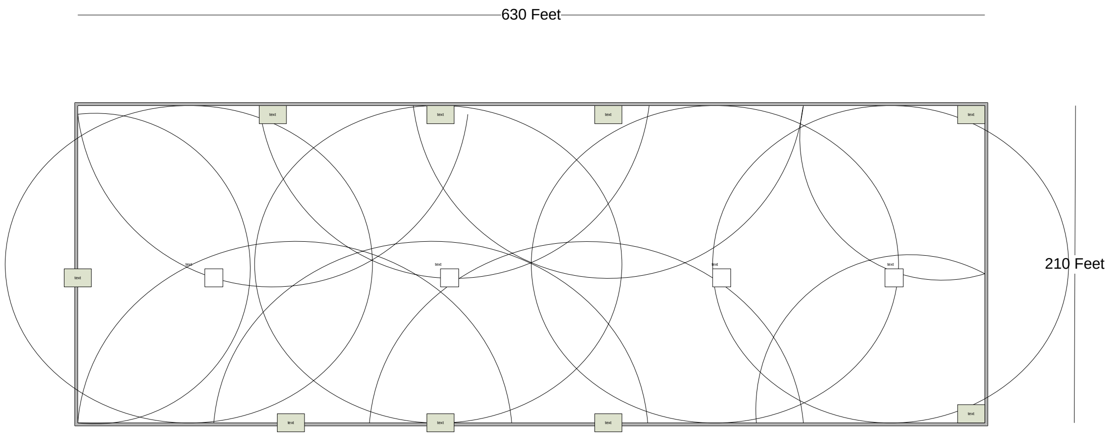
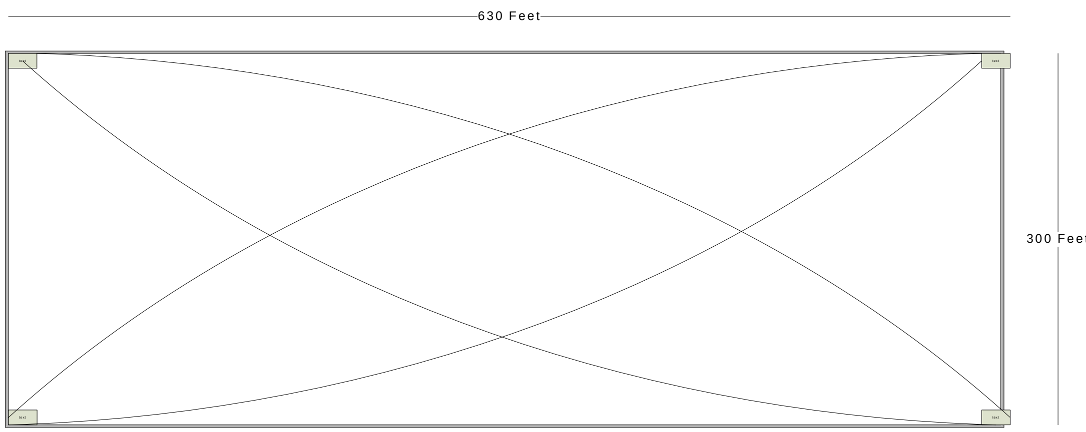


Figure 4: Reader layout for the Yard: 4 directional readers for added reliability (2 readers sufficient)



Using Passive Tags

Coverage limited to 4-5 feet hence readers placed every 9-10 feet. Following assumptions are made:

1. Cover 2/3 of the warehouse 'open' spaces
2. Additional readers at designated areas such as docks, doors and shelf locations.
3. Ceiling is 30 feet high. Readers will hang 15 feet down in open spaces (1 reader every 9 feet).

Racks: 5 racks of 150 feet x 18 feet. Each rack requires 24 readers (120 readers for full coverage).
Doors: 8 readers.
Open spaces in 2/3 of the warehouse: 900 readers.
Outdoor yard: no feasible solution with passive tags.

In addition to 1028 readers, the passive technology based solution requires:
Software (communication & management layer) and special communication layer for the readers and the infrastructure (multiple servers are required to handle network of readers and data model).

Estimated Cost Comparison

Pharmaceutical example used in this sketch used 340,000 tags on pallets, boxes and high value items. The observation is that all pallets are tagged (23,000 pallets) but only 25% of the boxes are tagged (115,000) and 2% of the high value items are tagged (202,000). Average 3PL pharmaceutical DC is 124,000 sq ft and transacts goods worth $ 775 million per annum, made up of about 20,800 SKU's (49% pharmaceuticals and 27% non-prescription drugs). In US, the industry is worth $ 155 billion.

Table 1: Estimate of **<u>ratio</u>** of cost for Active UWB vs Passive RFID solution (reality = real word cost)

	Passive Low End	Passive in Reality	Active Low End	Active in Reality
340,000 Tags	$ 1.00	$ 2.67	$ 5.07	$ 13.33
1028 Readers (P)	$ 137.07	$ 479.73		
15 Readers (A)			$ 1.00	$ 4.00
Server & Software	$ 3.00	$ 33.33	$ 1.00	$ 33.33
SI work	$ 1.50	$ 2.50	$ 1.00	$ 1.25
Total	$ 1.89	**$ 5.45**	$ 1.00	**$ 2.25**
System Complexity	Very High (1028 readers)	Very High (1028 readers)	Low (15 readers)	Low (15 readers)

Temporary Conclusion

Implementation cost of passive RFID may be nearly two and half times (2.5) more expensive (with a very high system complexity) compared to a low complexity implementation using active UWB tags.