RFID Resource Network Report

RFID Technology Roadmap

Wireless Smart Systems and RFID

Project acronym: *RFID-RNET*

Project full title: RFID Resource Network

RFID Contribution to Strategic Research Agenda Smart Systems Integration

Flexible, 64-bit organic RFID tag

Source: IMEC

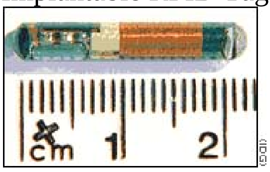
RFID Logger

Source: Evidencia

Ultra-Thin Flexible RFID Tag

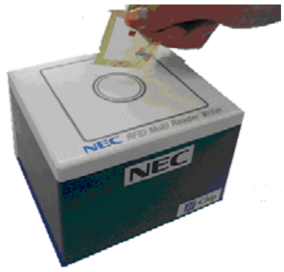
Source: Semiconductor Energy Laboratory and TDK

Implantable RFID Tag



Source: VERICHIP

RFID Multi-Reader/Writer



Source: NEC

NFC RFID Mobile Phone

Source: NOKIA

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Table of contents

1 Wireless Identifiable Smart Systems

1.1 Vision

The vision of Future Internet based on a standard communication protocol consider the merging of computer networks, Internet of Media (IoM), Internet of Services (IoS) and Internet of Things (IoT) into a common global IT platform.

The Internet of Things will form the wireless, self-configuring, network between objects/things and will be pervasive, and ubiquitous. Wireless identifiable smart devices, embedded in smart materials, will work in synergy to make information available anywhere at any time by relying on connectivity and communications, using hybrid networks of devices and sensors/actuators to meet the 'anywhere' requirement in order to improve the quality of life and reduce the negative impacts on the environment.

Considering the functionality and identity as the basic features, the "Internet of Things" could be defined as "the network form by things/objects having identities, virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate with user, social and environmental contexts". Using this network, mobile robots and wireless identifiable smart devices will be able to seamlessly interact and communicate with the environment, thereby contributing to the efficient, secure and inclusive nature of our society.

Wireless identifiable devices (EMID-Electro Magnetic ID: USID-Ultra Sound ID, RFID-Radio Frequency ID, MMID-Millimetre waves ID, etc,) will form the backbone of "Internet of Things" infrastructure allowing new services and enabling new applications that require extensive *machine-to-machine* communications.

The Internet is also revolutionising the Enterprises and businesses environments, with the introduction of RFID technologies enabling more automated processes. These open the way towards an Internet of Things, where multiplicity of tags, sensor, and actuators provide physical world information enabling new classes of applications combining virtual and physical world information.

The wireless identifiable devices and tags used in the Internet of Things infrastructure will have different shapes and forms and will require communication, processing, memory, sensing capabilities, privacy and security features. The tags should be recycled or biodegradable and the price and functionality of the tags will decide the extent of their application. Applications will range from logistics to defence and the tags will be used throughout the manufacturing and logistic supply chain to provide traceability or more complex monitoring, 3D localisation and positioning.

There are 900 million PCs, more than 1 billion Internet users, more than 3.2 billion mobile phone subscribers and 10 billion microprocessors were shipped 2007. Today, already more than 2 billion RFID tags are in operation and the number is expected to increase dramatically in the next few years. The "Internet of Things" is the network of billions or trillions of such machines (wireless identifiable devices) communicating with one another and is based on concepts like:

- Ubiquitous communications
- Pervasive computing
- Ambient intelligence

The Internet of Things represents a fusion of the physical and digital worlds that creates a map of the real world within the virtual world by using a high temporal and spatial resolution and combining the characteristics of ubiquitous sensor network and other wireless identifiable devices while reacting autonomously to the real world and influence it by running processes that trigger actions, without the direct human intervention.

1.1.1 ID

Simple tags/devices have as their basic functionality to provide wirelessly an ID number. The devices require no line-of-sight and can be read as long as the tagged item is within range of the reader. The tags are simple, low cost, disposable, and implemented using ultra polymer, SAW, or low cost silicon technologies. The tags are using RF waves to identify animals, track goods logistically and replace printed bar codes at retailers. RFID tags include a chip that typically stores a static number (ID) and an antenna that enables the chip to transmit the stored number to a reader via electromagnetic waves. When the tag comes within range of the appropriate RF reader, the tag is powered by the reader's RF field and transmits its ID to the reader. RFID middleware provides the interface for communication between the interrogator and existing company databases and information management systems.

1.1.2 Beyond ID

The development of smart systems implies new devices that go beyond wireless identification and include processing capabilities, sensing/monitoring, larger non-volatile memories and combining multi standards and multi communication protocols (NFC, RFID, UWB, Rubee, Zigbee, Wi-Fi, or others) to interconnect with other ubiquitous sensor networks and to implement Real Time Location Systems (RTLS). Applications of wireless identifiable smart systems will be beyond the ID information in many areas such as:

- Ambient Intelligence and ubiquitous computing
- Hybrid wireless sensor networks that are characterised by modularity, reliability, flexibility, robustness and scalability.
- Systems using different communication protocols
    - RFID
    - ZigBee
    - Rubee
    - Ultra low power Bluetooth
    - WiFi
    - WirelessHART
    - ISA100.11a
- Wireless monitoring of different ambient parameters (video, audio, temperature, light, humidity, smoke, air quality, radiation, energy, etc)
- Mobile robotic sensor networks.

These developments will enable the development of new context and situation based personalised applications and services:

- User context identification
    - Biometrics
    - Privacy mood
    - Attention
    - Gesture
    - Posture
- Social context
    - Surrounding people and/or objects/things
    - Type of group
    - Link to people and/or objects/things
    - Net link - Internet of Things
- Environmental context
    - Location, position
    - Time
    - Condition
    - Physical data

1.1.3 Beyond RF

Wireless communications using the frequency spectrum beyond the radio frequency range.

Range		Frequency Range	Wavelength	Frequency	Standard
LF	Low Frequency	30kHz to 300kHz	10km to 1km	30-50kHz 125/134kHz[1] 131/450kHz	USID 18000-2 IEEE P1902.1/ RuBee
MF	Medium Frequency	300kHz to 3MHz	1km to 100m		
HF	High Frequency	3MHz to 30MHz	100m to 10m	6.78MHz[2] 7.4-8.8MHz 13.56MHz 27MHz	18000-3 ISO/IEC 15693 ISO/IEC 14443/NFC ISO/IEC 10536
VHF	Very High Frequency	30MHz to 300MHz	10m to 1m	125MHz	
UHF	Ultra High Frequency	300MHz to 3GHz	1m to 10cm	433MHz 840-956MHz 2.45GHz	18000-7 18000-6 Type A, B. C EPC C1G2 IEEE 802.11 18000-4 IEEE 802.15 WPAN IEEE 802.15 WPAN Low Rate IEEE 802.15 RFID
SHF	Super High Frequency	3GHz to 30GHz	10cm to 1cm	3.1-10,6GHz 5.8GHz 24.125GHz	IEEE 802.15 WPAN UWB 18000-5
EHF	Extremely High Frequency	30GHz to 300GHz	1cm to 1mm		MMID

[1, 2] According to Annex 9 of the ERC Rec 70-03, inductive RFID Reader systems primarily operate either below 135 kHz or at 6.78 or 13.56 MHz. Therefore the correlated transponder data return frequencies reside in the following ranges:

LF Range Transponder Frequencies: $f_C = < 135$ kHz, $f_{TRP} = 135$ to 148.5 kHz
HF Range Transponder Frequencies: $f_C = 6.78$ MHz $f_{TRP} = 4.78$ to 8.78 MHz
$f_C = 13.56$ MHz $f_{TRP} = 11.56$ to 15.56 MHz.

The future Internet of Things will be based on heterogeneous networks of wireless identifiable devices connected with wireless ubiquitous sensor networks with systems continuing use different LF frequencies (USID, RFID) and to adopt existing licence-free bands including 13.56MHz, 433MHz, 840-956MHz, 2.4GHz and 5.8GHz. The main issue for these networks will be the crowding of bands and the power levels used.

1.2 Technology

Maintaining European industry leading role in mobile communication systems requires increasing the research efforts for developing and deploying EMID, smart radio tags, wireless identifiable smart systems and ubiquitous sensor network to make use of the potential offered by the future Internet of Things. .

The technology needs to ensure that further development and deployment of smart radio tags and wireless identifiable smart systems are as safe, secure, privacy-friendly and effective as possible and are taking into account interoperability, harmonising standards and radio frequency allocation, while also sufficiently guaranteeing individuals' privacy and security.

Developing wireless identifiable smart systems with data transfer rates < 1Mbit/s, micro operating systems, software, new power efficient communication algorithms, innovative adaptable, self organising and self healing architectures requires a concentrated research effort addressing the following key enablers:

1.2.1 Energy

The development of new batteries (fuel cells, printed/polymer batteries etc.), new energy generation devices using coupling energy transmission methods or energy harvesting using the energy conversion together with compact energy storage devices will be the key factors for implementing autonomous wireless smart systems.

1.2.2 Intelligence

Development of ultra low power processor/microcontroller cores designed specifically for mobile IoT devices (MIoTDs) and a new class of simple and affordable IoT-centric smart systems will be a priority. The solutions in this respect will range from the use of hard wired or micro programmed finite state machines to the use of microcontrollers. The choice is a trade off between flexibility, programmability, silicon area and power consumption.

The devices require some form of non-volatile storage (EEPROM/FRAM/Polymer), whether laser trimmed at the time of manufacture, one time programmable, or electrically rewritable. Rewritable non-volatile memory is clearly preferred for achieving high throughput during production test, and concurrently offers the benefit of user memory, programmability and storage for sensing data. Research topics are: life data retention, read/write capability cycle and embedded memory capacity.

1.2.3 Communication

New, smart beam steer able phased array antennas and multi frequency band antennas, integrated on chip made of new materials are the communication means that will enable new devices to communicate. On chip antennas (OCA), coil on chip, printed antennas, embedded antennas and multiple antenna using different substrates and 3D structures will be optimised for size, cost and efficiency. Modulation schemes, multi frequency energy efficient communication protocols, transmission rates, and transmission speed are also technology drivers.

The communication protocols will be designed for Web oriented architectures of the Internet of Things platform where all objects, wireless devices, cameras, PCs etc. are combined to analyze location, intent and even emotions over a network. New methods of effectively managing power consumption at different levels of the network design, from network routing down to the architecture of individual devices.

1.2.4 Integration

The use of integration of chips and antennas into non-standard substrates like textiles and paper, and the development of new substrates, conducting paths and bonding materials adequate for harsh environments and for ecologically sound disposal will continue.

System-in-Package (SiP) technology allows flexible and 3D integration of different elements such as antennas, sensors, active and passive components into the packaging, improving performance and reducing RFID tag cost. RFID inlays with a strap coupling structure are used to connect the IC chip and antenna in order to produce a variety of shapes and sizes of labels, instead of direct mounting.

1.2.5 Interoperability

The future standards must ensure that RFID tags and readers work globally. Future tags must integrate different communication standards and protocols that operate at different frequencies and allow different architectures, centralised or distributed, being able to communicate with other networks.

1.2.6 Standards

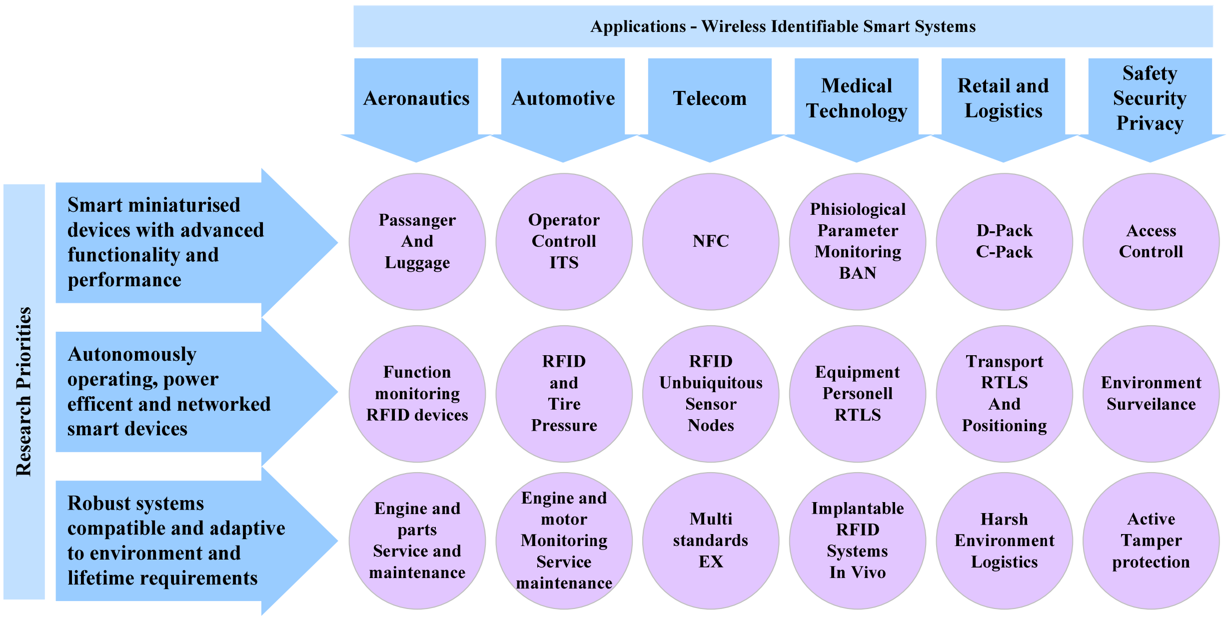
Royalty-free open standards that allow tags to be read seamlessly across different countries are key enablers for the success of RFID technology, for M2M communication. In order for RFID to successfully penetrate into large open systems, RFID interoperability is a necessity. Standards evolution and interoperability will influence the RFID deployments in the near future. Sustainable fully global, energy efficient communication standards that are security and privacy centred and are using compatible or identical protocols at different frequencies are needed. The interest at the European level is the near future will be:

- To align RFID standards development globally
- To create a number of liaison activities to disseminate information about the importance of global standards
- To put in place the interoperability groups comprising global stakeholders
- To ensure continuous close collaboration between standards activities

1.3 Applications

Many applications are now using wireless identifiable devices (EMID-Electro Magnetic ID: USID-Ultra Sound ID, RFID-Radio Frequency ID, MMID-Millimetre waves ID, etc,) to automatically identify objects or people. While a variety of applications use the electromagnetic waves to communicate information, the wireless technology used (antenna, chip, assembly, power generation, sensing/actuating capabilities) for each is quite different, addressing unique storage, range and security requirements. Wireless identifiable device technology is used in applications that identify, track, sense, monitor and locate objects or people while contactless smart card technology is used in applications that identify people or store financial or personal information.

Diffrent application areas are foreseen to use in the future the IoT and they range from automatic meter reading, home automation, industrial monitoring, military, automotive, aeronautics, consumers (Personal Area Networks), retail, logistics (shipping tracking storing, managing supply chain), food traceability, agriculture, environment and energy monitoring to healthcare and pharmaceutical. Few of these applications areas are described in more details in the next paragraphs.



1.3.1 Aeronautics

The use of dynamic monitoring systems by employing RFID and wireless identifiable sensing devices to provide input during the life-cycle phases of production, operation disposal of aircrafts and components. This will require robust RFID and sensor technologies. These will need to have in-service lives of 25-30 years, and be able to operate in harsh environments (for example, with large variations in temperature, humidity, material use, and corrosion).

The aeronautics industry will develop new ways of using innovative RFID and wireless sensing technologies to track and monitor parts, components and structures (their production, operation and dismantling) in order to minimise the environmental impacts that are caused by air transport. In the area of aircraft operation, innovative wireless monitoring/feedback systems will be used for reducing energy consumption and environmental impacts during flights.

With RFID and wireless sensors technologies implemented in the aeronautics industry, all stakeholders in the industry - parts manufacturers, logistics service providers, aircraft manufacturers, airline operators, service and maintenance operators, recycle operators, and consumers - will have better visibility of aircraft components and parts during the aircraft life cycle and have the possibility to evaluate how these aircraft components and parts could affect the environment.

The wireless identifiable devices attached to the aircraft components and parts can be updated with warranty and repair information to provide a virtual pedigree on each device, and these devices can help ensure that manufacturers comply with regulatory mandates for disposal of toxic substances (products that contain lead, mercury and other hazardous substances - Restriction on Hazardous Substances - RoHS directive).

This will result in the development of a complete systematic scheme to assess the environmental impact of the products throughout their entire life, targeting design, procurement, manufacturing, transport, in-service operations, including maintenance, aircraft end of life and recycling.

The implementation of advanced wireless identifiable devices and RFID sensing technology will require developments of smart devices with more memory (non volatile) allowing the capture of large numbers of data continuously over a long period of time. This will improve two functions essential for documentation and post processing: consistency and the luxury of recording a wide range of parameters simultaneously.

The "on-condition' wireless monitoring of the aircraft by using RFID intelligent devices with sensing capabilities disposed within the cabin or outside and connected to the aircraft monitoring systems is another emerging application area that forms the basis for ubiquitous sensor networks.

The nodes in such a network will be used for detecting various conditions such as pressure, vibrations, temperature etc. The data collected gives access to customized usage trends, facilitates maintenance planning, allows on condition maintenance, reduce maintenance and waste and will be used as input for evaluating and reducing the energy consumption during aircraft operations.

Safety - the challenge of sustaining the confidence of both the passenger and society that commercial flying will not only remain extremely safe, notwithstanding greatly increased traffic, but will reduce the incidence of accidents. In this context wireless identifiable systems will be developed using:

- RFID tags correlated with luggage in containers, RFID tag based passenger/luggage/cargo tracking concepts
- RFID tags and sensors on conveyors; cost effective reading system linked to overarching security database; CCTV and data imaging software

Life Cycle

- The processes of design and manufacture in the aeronautics industry will be increasingly automated with assembly increasingly featuring standard modules and integration of RFID technologies. Innovative active RFID control devices with the possible use of MEMS
- Smart maintenance systems using RFID and condition monitoring for increased service intervals
- Digital integration of the supply chain/virtual companies and programmable system functionality, data exchange/inter-subsystem communication technology, energy management technologies for cost effective upgrades during the life cycle (open system architectures).

1.3.2 Automotive

Applications in automotive industry include the use of RFID devices to monitor and report everything from pressure in tires to proximity of other vehicles. RFID technology is used to streamline vehicle production, improve logistics, increase quality control and improve customer service. The devices attached to parts contains information related to the name of the manufacturer and when and where the product was made, its serial number, type, product code, and precise location in the facility at that moment. RFID technology provides real-time data in the manufacturing process, maintenance and offers a new way of managing recalls more effectively.

The use of wireless identifiable devices helps the stakeholders to gain insight into where everything is so it is possible to speed assembly processes, locate cars or components in a fraction of the time. RFID technology is ideal in enabling real-time locating systems (RTLS), improving vehicle tracking and management and supporting automotive manufacturers better manage the process of testing and verifying vehicles coming off the assembly line while tracking them as they go through quality control, containment and shipping zones..

1.3.3 Telecommunications

RFID is merging with other telecommunication technologies and one of the applications is NFC (Near Field Communication) and sensor networks. In these type of applications the RFID Reader/tag in the heart of the mobile phone, i.e. on the SIM-card. NFC is a short-range RFID wireless technology optimized for communications between various devices without any user configurations. NFC makes objects communicate in a simple and secure way just by having them close to each other. The mobile phone can therefore be used as a NFC-reader and transmit the read data to a central server. When used in a mobile phone, the SIM-card takes an important role as storage for the NFC-data (like ticket numbers, credit card accounts, ID information etc)

1.3.4 Medical Technology

Cell phone RFID-sensor reader platform technology for glucose monitoring and insulin delivery by using a disposable, wireless skin patch that measures glucose levels and reports those levels to a cell phone that could also wirelessly control an insulin pump. The patches could be designed to provide readings once every hour for a 24-hour period. Using cell phones as readers has many benefits, including emergency geo location of patients.

Advanced RFID technologies will also reshape pharmaceutical and medical applications. Electronic tags will carry information related to drug use making it easier for the customer to be acquainted with adverse effects and optimal dosage. RFID enhanced pharmaceutical packaging can carry not just all related information, but also control medical compliance. Finally smart biodegradable dust embedded inside pills can interact with the intelligent tag on the box allowing the latter to monitor the use and abuse of medicine and inform the pharmacist when new supply is needed. The smart dust in pills could also know incompatible drugs, and when one is detected close enough the pill could refuse to activate or release the active substances. Chemotherapy treatment management and chronic infection can be as well monitored and managed with the use of RFID. The combination of sensors, RFID and NFC (near field communication) will allow a significantly improved measurement and monitoring methods of vital functions (temperature, blood pressure, heart rate, cholesterol levels, blood glucose etc).

The enormous advantages are to be seen on the one hand side in prevention and easy monitoring (and having therefore an essential impact on our social system) and on the other side in case of accidents and ad hoc diagnosis. Especially passive RFID could act as communication as well as power interface for medical implants.

Implantable wireless identifiable devices could be used to store health records that could save patient's life in emergency situations especially people with diabetes, cancer, coronary heart disease, stroke, chronic obstructive pulmonary disease, cognitive impairments, seizure disorders and Alzheimer's, and people with complex medical device implants, such as pacemakers, stents, joint replacements and organ transplants and which up in an emergency room, unconscious and unable to communicate for themselves. Use RFID for medicine delivery by guiding nanobots with RFID positioning capabilities the implantable device to the chosen location in the body and than sending a command to release the medicine. Eatable, biodegradable chips that can be introduced into the body and used for guided action. Paraplegic persons could have muscular stimuli delivered via an implanted RFID controlled electrical simulation system in order to restore movement functions.

In this context security, privacy and safety by design will be a first priority for the implantable wireless identifiable devices development and use.

1.3.5 Retail and Logistics

Initially, the RFID technology was studied in order to replace the bar code in retail. The adoption of RFID, although started in several pilot projects and exhibitions, has been slowed down by several factors, such as the much higher cost of the tag over the bar code, some needed technology improvement for what concerns transmission of metals and liquid items, and privacy concerns. The electronic tags offer multiple benefits over the bar code for both the retailers and the consumers. The retailers will have item identification unified from the producer, through the storage, the shop floor, cashier and check out, as well as theft protection. The shelves can issue refill order automatically, and the history of any item from production to the shelf can be stored offering increased quality management along the supply chain. For the consumers this offers the possibility to avoid long check-out lines, and having the product history available will improve food safety and protect consumer rights in case of failing products.

Another important application field is logistics. Warehouses will become completely automatic with items being checked in and out and orders automatically passed to the suppliers. This will allow better asset management and proactive planning on behalf of the transporter. Executable code in the tags will enable future smart objects to make intelligent decisions on their own routing based on information received either via readers or positioning systems. This will help optimising, both locally and globally, the forwarding of items and delegate routing authority from the transporter to the manufacturer or the customer.

1.3.6 Safety, Security and Privacy

Wireless identifiable devices are used in different areas to increase safety and security. Some of these are:

- Environment surveillance: earth quakes, tsunami, forest fires, floods, pollution (water and air).
- Building monitoring: water leaks, gasses, vibrations, fire, unauthorised entry, vandalism.
- Personnel: mugging alarm, equipment surveillance, payment systems, identity security

When using wireless identifiable smart devices, opportunities and threats could arise from the proliferation of data, the sharing of the data, and from the possibility of snooping via radio. Deciding a common strategy and a policy for future Internet of Things was a priority for European Commission, which considers that each datum itself in its integral parts is not a threat but this could become a treat when associations are built with accessed databases that sensitive relationships are revealed or discovered, resulting in damage or potential for damage.

1.3.7 Energy and Environment

Wireless identifiable devices and the utilization of RFID technologies in green related applications and environmental conservation are one of the most promising market segments in the future, and there will be an increased usage of Wireless identifiable devices in environmentally friendly programmes worldwide.

Today, RFID is being used to advance the efficiency and effectiveness of numerous important city, and national environmental programmes, including the monitoring of vehicle emissions to help supervise air quality, the collection of recyclable materials, the reuse of packaging resources and electronic parts, and the disposal of electronic waste (RFID used to identify electronic subcomponents of PCs, mobile phones, and other consumer electronics products to increase the reuse of these parts and reduce e-waste). RFID continues to provide greater visibility into the supply chain by helping companies more efficiently track and manage inventories, thereby reducing unnecessary transportation requirements and fuel usage.

Autonomous networked wireless identifiable devices with physical sensors that combine advances in sensor miniaturisation, wireless communication, and micro-system technology will form the ubiquitous sensor networks that can make accurate measurements of environmental parameters (temperature humidity, light, acceleration etc.) in buildings and private homes. Building energy control systems are but the next application of wireless identifiable devices by bringing the possibility of accurate climate control for all buildings down to individual house level.

Standardisation efforts are considering the data rates of up to 1Mb/s, heterogeneous sensor integration and different frequencies. This will open up new applications with positive impact on society, such as remote data monitoring in disaster scenarios, ubiquitous connectivity for health monitors in body area networks, and wireless broadband for rural areas. Secure communications are also a concern of end users. In the meantime, operators are looking beyond the capital expenditure costs of running RFID networks to minimising operational costs such as power consumption and site costs.

1.4 Challenges in developing RFID and Wireless Identifiable Smart Systems

Wireless Identifiable Smart Systems will require efficient use of frequency spectrum scarcity, multi band RFID solutions that will provide the required bandwidth to deliver data rates up to 1Mbit/s. Advances in filtering, matching, and analog RF processing technologies, along with their heterogeneous integration with RF MEMS will be needed for tuneable and multi-band operation.

Short range communication (DSRC) will also give the possibility of higher bit rates and reduce the possibility of interference with other equipments. DSRC could be used as well in the future for RTLS.

To minimise RFID reader size, ultra compact active tags combined with radio processing (e.g. mixing, passive and active filters) will be achieved through advances in SiP (system-in-package) integration of heterogeneous technologies such as MEMS, SAW (Surface Acoustic Wave), active and passive electronics.

Wireless identifiable devices based on surface acoustic waves (SAW) could be an interesting solution for some niche application due to the fact that they are passive devices and do not demand any power source. Other advantages could be the read range the die size, the cost, operation at high temperatures (up to 200ºC) and even under a high dose of radiation. For SAW RFID tags the RF interrogation signal is sent by the reader to the tag antenna and the signal is converted by an inter digital transducer into a SAW pulse that propagates along the surface of a piezoelectric substrate. The reflectors placed in the propagation path of the SAW partly reflect the wave back towards the inter digital transducer. The positions of the reflectors are used for coding of the reflected wave. The coded SAW returning to the inter digital transducer is reconverted into an electric signal and radiated back to the reader.

To minimise RFID readers' site costs, miniaturisation in RF subsystems will be used in low-profile smart remote radio heads.

Hardware solutions for RFID readers form the necessary "layer 0" in the communications protocol stack, and the above solutions require more than just software or new algorithms or innovative architectures: advances in heterogeneous hardware solutions, at the core of smart system solutions.

Achieving hardware that is adaptable *and* provides high performance, requires a close integration in the one package of micro-scale mechanical, digital and active plus passive RF technologies.

Smart devices often have limited local information and cognitive capabilities. Networking the devices results in a better informed, more intelligent overall system. Connecting the RFID devices with other wireless networked devices is a necessary underlying component of many smart systems. Delivering that connectivity in an affordable, effective manner requires major improvements in many dimensions:

Advances in RF antenna and filter design, packaging and module integration will enable miniaturisation of wireless identifiable devices and RFID readers. New circuit design techniques and micro-generation techniques for power will extend the operational life of remote devices.

Integration of NEMS, MEMS, BAW (Bulk Acoustic Wave) and SAW devices, and classical integrated circuitry, both active and passive, will also drive down the size of RFID tags and readers. Co-simulation of the various technical domains, electrical, mechanical, and acoustic, will be required for optimised solutions and low time-to-market.

New scalable architectures designed specifically for the ubiquitous sensor networks communications will allow for networks of billions of devices. Improvements in techniques for secure and reliable RFID communication protocols will enable mission-critical applications for ubiquitous sensor networks based on wireless identifiable devices.

The business models for RFID and ubiquitous sensor networks will be new service and system providers to service the communication demands of potentially tens of billions of devices. Three main trends are seen today:

- Ultra low cost tags with very limited features. The information is centralized on data servers managed by service operators. Value resides in the data management.
- Low cost tags with enhance features extra memory and sensing capabilities. The information is distributed both on centralized data servers and tags. Efficient network infrastructure. Value resides in communication and data management.
- Smart fix/mobile tags. More functions into the tag bringing local services. Smart systems (sensing/monitoring/actuating) on RFID tags. The information is centralized on data tag itself. Value resides in the communication management.

Smart devices enhanced with inter-device communication will result in smart systems with much higher degree of intelligence and autonomy. This will enable the more rapid deployment of smart systems discussed elsewhere in this Strategic Research Agenda, with all the benefits accruing to European society as listed. For example, vehicle-to-vehicle and vehicle-to-infrastructure communications will significantly advance Intelligent Transportation Systems (ITS) applications such as vehicle safety services and traffic management.

2 Research agenda

Research is needed in the following technology areas:

The ability to communicate with either other nodes or the main network infrastructure is an essential characteristic shared by many smart systems. This holds across a wide range of applications, from health monitoring to remote water quality sensors, from automobile corner control units to smart utility meters. The requirements on the communications transceivers needed are similar across a wide range of smart system applications:

- High degree of miniaturization
- Extreme power efficiency
- High spectral efficiency
- Secure communications
- Low cost
- High degree of scalability across aggregations of very large numbers of devices

The roadmap for the realisation of the IoT includes several topics and steps. Between those, three are seen as a priority:

- Harsh environments
- Privacy and Security
- Energy Harvesting
- Peer-to-Peer communication models
- Automatic code generation theme for autonomous objects
- Protocol transfer of centralized algorithms for IoT

2.1 Advances in RFID antennas

Applications of wireless identifiable systems call for different type of antenna solutions that fit within ultra small volumes (from μm^3 to mm^3), consume ultra-low power (μWs level) and are used for frequencies covering existing and emerging standards and protocols, having different type of substrates, and operating in normal or harsh environments. .

Research should address the antenna and smart adaptive matching schemes, and the development of intelligent antenna for improving range and reducing required RF power levels. Focus will be on:

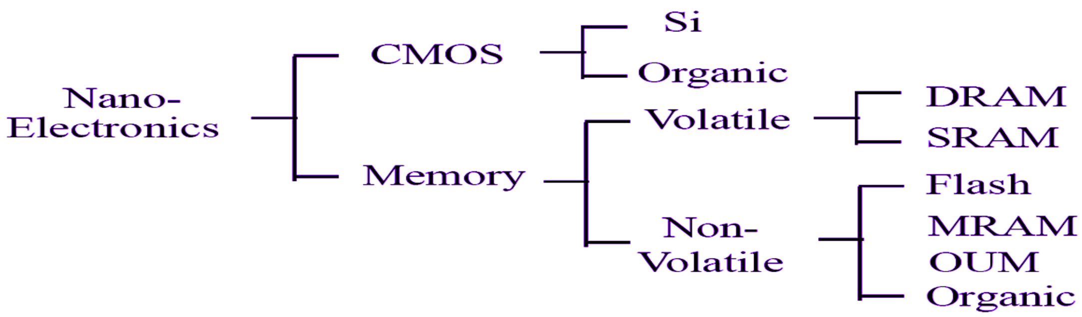
- On Chip Antenna (UHF, SHF)
- Coil on Chip (HF)
- Printed antennas (low cost)
- Embedded antennas
- Multiple antenna substrates
- 3D structures
- Harsh environment tolerant antennas and substrates

For RFID readers the focus will be on small size, strongly directional multi band reader antennas in order to improve reading range, control reading areas and reduce both reader-to-reader interference and power consumption. Low cost will be an important factor in choosing the technology, the substrate and the implementation.

2.2 Advances IC and polymer electronics technology:

There is a development of different technologies for wireless identifiable devices

RFID Technology Roadmap



The research on nanaoelectronics devices will be used for implementing RFID and wireless identifiable systems with the focus on miniaturization, low cost and increased functionality.

Polymers electronics technology will be developed and research is needed on developing cheap and even disposable electronics for implementing RFID tags and sensors that include logic and analogue circuits with n and p type Thin Film Transistors (TFTs), power converters, batteries, memories, sensors, active RFIDs.

Silicon IC technology will be used for systems with increased functionality and need for more non volatile memory used for sensing and monitoring ambient parameters. Research is needed on ultra-low power, low voltage and low leakage design in submicron RF CMOS technologies, on high-efficiency DC-DC power-management solutions, ultra low power, low voltage controllable non-volatile memory, integration of RF MEMS and MEMS devices. The focus will be on highly miniaturised integrated circuits that will include:

- Multi RF Front Ends
    - HF/UHF/SHF/EHF
- Memory –EEPROM/FRAM/Polymer
- ID 128/256 bits + other type ID
- Multi Communication Protocols
- UWB
- Digital Processing
- Security

Based on this development two trends are emerging for RFID and wireless identifiable devices:

- Increasing use of “embedded intelligence”
- Networking of embedded intelligence

2.3 Advances in packaging and module integration for miniature, low-power designs

To meet performance, cost and reliability requirements while achieving dramatic size and height reductions, new ultra miniaturised packaging approaches are required. Targets for the technology development will be:

- Low cost materials and fast processes
- Improvement of performance
- Miniaturization

Research is needed to address the assembly and packaging needs for two main categories of RFID and wireless identifiable devices:

- Devices integrated with other electronic products,
- Devices dedicated only for some specific functions and for short-distance communication

The challenge will be miniaturisation, ultra-small (μm^3-level), ultra-slim (few 100μm), flexible (wearable/stretchable), and/or harsh environment operation (temperature variations, vibration and shocks conditions and in contact with different chemical substances).

Label integration with flexible/stretchable substrates and interconnects to thin film discrete devices and thinned polymer and silicon ICs. Specific challenges are low cost processes by using one step foil lamination/interconnect vias, foil passivation; multi-foils system design and integration; and reliability.

System in Package (SiP) modular RFID/NFC reader devices Distributed decentralized data processing and storage in RFID/NFC systems with extensible data structures to allow integration of RFID/NFC in different applications. Multi frequency reader's solutions that can be used alone or plug in a PDA.

2.4 Sensing/actuation integration. Hybrid polymer/silicon/NEMS/MEMS wireless identifiable smart systems.

High-performance integrated radio technology is moving towards embedding a variety of HF-, UHF- and VHF-MEMS technology to enhance the radio performance while reducing the volume and cost. Submicron CMOS provides the processing capability, low cost, low power consumption, which will enable the implementation of smart RFID and wireless identifiable systems. Polymer electronics will be used for low cost biodegradable wireless identifiable systems. Both developments will require heterogeneous integration with other technologies and special focus will be to integrate new sensing technologies in such devices.

Research is need to develop ultra low cost and ultra low power sensors based on MEMS/NEMS, polymer technologies (temperature, pressure, humidity, shock, vibration, etc) and integrate them with silicon CMOS interfaces and polymer electronics devices.

2.5 Energy harvesting, micro-generation and power management

Power supply and power management are critical components of the RFID and wireless identifiable blocks for any smart system. This is particularly the case for widely deployed aggregations of wireless sensor nodes with a high degree of autonomous operation and ultra-small physical form factors.

Research is also needed into modelling, simulation and prediction of energy use for improved energy efficiency and automatic configuration algorithms for optimization and how is possible to get the energy from different networked grids.

Research is needed on developing energy harvesting and super capacitor systems for powering RFID, wireless identifiable devices and large ubiquitous sensor networks.

Research will concentrate on developing micro generators that support the power requirements of intermittent ubiquitous sensor systems in industrial applications and energy storage (i.e. super capacitors, etc) that provides the required peak power for data transmission and data sensing/monitoring.

Research focus will be on power harvesting and generation using:

- RF waves
- Micro solar generators
- Harvesting micro devices (vibration, temp, etc.)
- Batteries: flat, printed/polymer
- Micro Fuel cells

2.6 Architectures modules and sub systems

Innovative miniaturised/highly integrated wireless identifiable smart systems for the "Internet of Things". Emphasis is on extreme miniaturisation for multifunctional portable and networked applications, solutions for adaptable LF, HF, UHF, VHF technologies, such as smart RFID, ultra-low power radios and reconfigurable antennas. Developing smart devices for ubiquitous sensor networks and continuing to adopt existing licence-free bands including 13.56MHz, 433MHz, 868MHz, 2.4GHz and 5.8GHz.

Passive RFID and wireless identifiable systems: Research on developing ultra low power savings architectural components, more efficient DC-DC circuits, low voltage controllable serial EEPROM and ultra low security algoritms. Research is needed on developing techniques to increase the amount of non-volatile memory in passive tags with minimal additional power requirements and solutions for implementing low power sensors and interfaces for passive RFID.

Active RFID and wireless identifiable systems: Research on developing power savings architectural components including a passive switch for active (battery powered) wireless identifiable, RFID tags, smart modules for reducing controller power consumption in active tags, a layered security approach that leverages features of RFID communications to improve security while limiting additional power requirements, and a technique to increase communication and integration of sensing capabilities. Research is needed on heterogenous integration with displays (Bi-stable, flexible, transparent) and actuators.

Research on dynamic reconfigurable embedded RFID readers for multi frequency multi protocol RFID/NFC applications.

Mobile NFC readers Small readers of the size of ca. 3cm x 3cm x 0.5cm are in few cases already embedded in mobile. Developing the next generation multi frequency multi protocol HF: 13.56MHz, UHF: 840-956MHz, MW: 2.45GHz modular readers.

Multi frequency multi standard modular mobile RFID/NFC readers Multi standard RFID/NFC readers that automatically switch from one standard to another adapt to the type of signal.

Research on developing modular platforms that will allow reading and writing any RFID device information available in any objects by supporting the major RFID/NFC global protocols/standards. The RFID/NFC for future IoT should have the following features:

- Reduced cost and complexity of developing and deploying intelligent RFID/NFC solutions and ubiquitous sensor networks
- Scalable architecture to meet the needs of different applications
- Low cost, small size reader device suitable for embedded, mobile and distributed RFID/NFC deployments
- Programmability and user defined commands for sensor/actuator based RFID/NFC tags.
- Network interface (Wi-Fi, etc.) and data interface (USB/SPI/RS232, etc.), high level of security for user authentication, role-based authorization and network communication leveraging existing standards
- A global reader that provides support across all product features for ISO, EPC, etc., and custom tags, offering flexibility for business logic and hardware/tag selection and tag encoding/decoding.

Embedded RFID/NFC reader for future applications should cover at least three RFID frequencies: HF/13.56MHz, UHF/840 – 956 MHz and MW/2.45GHz and implement multiple standards (NFC/ISO/IEC14443/ISO/IEC15693, ISO/IEC18000-6C = EPC global Class1 Gen2, and ISO/IEC18000-4 Mode 1,2/µ-Chip).

Research on embedded readers for harsh environments and explosive environments (EX type) and new assembly techniques for these types of RFID readers.

2.7 Secure communication data sharing, database use and data management

Research efforts are needed to define where data will it be stored? How will it be managed? What are backup/archive procedures? How will security and access be applied to the databases? With business leaning towards an easily programmable ubiquitous sensor network, how can new behaviours be introduced in a secure and controlled manner without compromising security? How will this network scale globally and across the supply chain?

In this context are necessary to develop policies notifying consumers and giving the consumers options to permanently disable or discard the tags without incurring cost or penalty. At the same time options should be provided to consumers so they can leave the tags enabled if the tags are integrated into their own personal network.

3 Research Priorities:

The roadmap for the realisation of the IoT is, as we can expect, long and obstacle ridden. Some of the most identifiable and key research priorities are listed below.

3.1 Intelligent systems

A clear research priority focuses on the **Intelligence** of the systems. As we saw in the section 2.2, context-awareness and inter-machine information exchange will be central to the IoT. In the coming period, there is therefore the need to study a global architecture for the IoT, where peer-to-peer communication models, the shift of already existing bio-inspired approaches from a centric view to a distributed one, in which intelligence is pushed towards the edge of the system, and the development of autonomic devices able to generate automatic code and behaviours, will play a central role.

The research priorities will focus on increasing and adapting the intelligence at the device level by the integration of sensors and actuators, new power efficient hardware/software security architectures, high efficient, multistandard and adapting front ends (SoC), adaptable antennas (smart beam steer able phased array antennas, multi frequency band antennas, on chip antennas (OCA), coil on chip, printed antennas, embedded antennas and multiple antenna using different substrates and 3D structures). The research will focus as well on non-volatile storage (EEPROM/FRAM/Polymer) necessary for programmability and storage for sensing data. Research topics are: life data retention, read/write capability cycle and embedded memory capacity

3.2 Energy sustainability

A strong accent will be put on energy efficient and **self-sustainable systems**. Novel ways to harvest energy from the environment must be explored and developed, in order to create systems that require little external energy, if any. Efficiency in processing and in communication must also be achieved through novel programming paradigms and the further development of energy efficient protocols and smart antennas.

Research efforts will focus on multimodal identifiable sensing systems enabling complex applications such as implants monitoring vital signs inside the body and drug delivery using RFID and harvesting the energy from different sources.

Research on printed batteries manufactured with sensor, thin film solar cells for energy harvesting, vibration and piezoceramic device for energy harvesting, wireless power supply to sensors and thin batteries with life of 10 years.

3.3 Privacy and Security

Many of today's concern about the wide adoption of the IoT lie in the popular belief that both privacy and security will be at risk. In order to reverse this belief, sound technological solutions must be developed, together with legislators at national and supra-national level. Extensive dissemination of the results of these discussions must also be undertaken by all IoT actors.

The research will focus on RFID with privacy control and energy efficient cryptography algorithms and using non-linkable digital transfers for disguising digital transactions. Combining different identification technologies to increase the security and privacy by using private, revocable ID for enabling users to be the sole owners of the objects identity.

3.4 Harsh Environments and Integration into Materials

Current trends show that the research process from application specific antenna design to smart antennas, suitable in different applications and materials, will finally lead to the integration of devices into non standard substrates. These substrates, and their operational fields, might have very specific requirements, and the resilience of these smart electronic components must therefore be extremely high.

Research will focus on RFID devices with sensing capabilities that are embedded in composite parts, by using antennas, integrated electronics, micro sensors, materials and special assembly techniques for operation in harsh environments (large temperature, pressure variations, etc) or implanted requiring biocompatible functionality.

3.5 Future Outlook

		Before 2010	2010-2015
Development	**Vision**	Connecting objects Pervasive RFID	Communicating objects Socially acceptable RFID
	Society	"Internet of Things" (IoT) concept debated Consumer concerns (privacy) Develop security and privacy mechanisms and establish security guidelines for RFID developers and operators of RFID systems Realising benefits (food safety, anti counterfeit, pharmacy) Changing ways to work Cultural barriers Data explosion Business process innovation	"Internet of Things" defined New business paradigms Ambient Intelligence Society Changing business (processes, models, ways to work) Distributed power grids Debate on authentication, trust and verification Environmental benefits Energy conservation Access rights issues
	Politics	De-facto governance Privacy legislation Energy consumption concerns Standardisation Energy and environment	Frequency Spectrum Governance Unified open interoperability EU governance Energy policy
	Standards	Standardization efforts for RFID security Creating a Gen2 standard of HF Extend the UHF Gen2 capabilities (security features) Standardization of passive RFID tags with expanded memory and read/write capability for product serial numbers, repair and warranty information. Radio regulation change to eliminate the listen before talk (LBT) requirement for improvement of dense reader mode RFID systems. Proposal for non-EPCglobal RFID standard (uID)	Privacy and security cantered standards Adoption of standards for "intelligent" IoT devices RFID global technology standards for product lifecycle tracking and monitoring (cradle to grave tracking/monitoring) Adoption of standards for different industries
	IT Systems and Services	Service oriented architectures Grid computing	IoT Browser and search engine Self management and control
	Infrastructure	Broadband	Grid network
	Network Technology	Photonic Wireless	Hybrid IPv6
	Business Impact	Globalization is a primary driver for RFID In US mandates from the U.S. Department of Defence (DOD) and Wal-Mart RFID adoption in logistics and retail Pharmaceutical Aeronautics and aerospace industry mandate to RFID tag all product shipments by 2010. Consolidation of providers in both the hardware and software markets. Industry specific solutions and expertise will continue to grow RFID market in exploration phase	RFID market in adoption phase Aeronautics Automotive Healthcare

3.6 Outlook Research Needs

		Before 2010	2010-2015
Research Needs	**Functionalities Features and Applications**	Low cost crypto primitives – hash functions, random number generators, etc. Low cost hardware implementation without computational loss Smaller and cheaper tags Higher frequency tags RFID tags for RF-unfriendly environments (i.e water and metal) 3-D localisation	Adaptation of symmetric encryption and public key algorithms from active tags into passive tags Protocols that make tags resilient to power interruption and fault induction. Power loss graceful recovery of tags More memory Less energy consumption Protocols for interoperability 3-D real time location/position embedded systems
	Ubiquitous Sensor Robotic Networks	Different networks (sensors, mobile phone, etc.,) Interoperability framework (protocols and frequencies) Network security (e.g. access authorization, data encryption, standards etc.)	Hybrid networks Ad hoc network formation Multi authenticfication Long range tags (higher frequencies –tenth of GHz) Networked RFID-based systems – interface with other networks – hybrid systems
	Power Generation	Thin batteries Energy harvesting Energy management RF Thermal Solar	Printed batteries Photovoltaic cells Super capacitors Energy conversion devices Grid power generation Multiple power sources
	Systems, Circuits and Architectures	Integration of hybrid technologies sensor, actuator, display, memory Power optimised hardware-software design Power control of system on chip (SoC) Development of high performance, small size, low cost passive functions e.g. high-Q inductors, tight tolerance capacitors, high density capacitors, low loss switches, RF filters, tuneable capacitors Mobile RFID readers with increased functionality and computing power while reducing the size and cost Miniaturised and embedded readers (SiP)	Multi protocol front ends Multi standard mobile readers Extended range of tags and readers Transmission speed Distributed control and databases Multi-band, multi-mode wireless sensor architectures Smart systems on tags with sensing and actuating capabilities (temperature, pressure, humidity, display, keypads, actuators, etc.) Ultra low power chip sets to increase operational range (passive tags) and increased energy life (semi passive, active tags).
	Devices	MEMS Low power circuits Silicon devices Smart multi band antennas Beam steerable phased array antennas Low power chip sets	Paper thin electronic display with RFID Ultra low power EPROM/FRAM NEMS Polymer electronics tags Antennas on chip Coil on chip

		Low cost tags Small size, low cost passive functions High-Q inductors High density capacitors, tuneable capacitors Low loss switches RF filters	Ultra low power circuits Electronic paper Harsh environments devices (extreme temperature variation, vibration and shocks conditions and contact with different chemical substances) Nano power processing units
	Materials and Processes	Polymer Silicon, Cu, Al Metallization 3D processes Assembly and packaging techniques for RFID tags (protection against high/low temperature, mechanical, chemical substances, etc)	Carbon Polymer Silicon Conductive ink Improved/new semiconductor manufacturing processes/technologies for higher temperature ranges Flexible substrates
	Environment Manufacturing	Vacuum plasma spray (VPS)	Industrial ecosystems