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MOTOROLA

The X-Internet

Connecting the Physical World with the Cyber World

WHITE PAPER

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Executive Summary

In just 20 years, the Internet has fundamentally changed the way we live, learn, do business and entertain ourselves. What makes the Internet so revolutionary is that it provides a standard way for people to connect anywhere around the world.

Now, the Internet is entering a new generation of Seamless Mobility, thanks to affordable mobile devices that take advantage of new options and increased coverage for wireless connectivity. Standards-based wireless technologies and infrastructure are growing at a rate that promises to completely remove all remaining barriers to truly seamless personal interaction and knowledge transfer.

But even a ubiquitous wireless Internet isn't the complete fulfillment of the Seamless Mobility revolution. Today's Internet connects people to people, providing information in text, video, sound and other formats intended for use by people. The next step is to Internet-enable physical objects — connecting people with things and even things with things.

The Extended Internet, or X-Internet, will enable connectivity not just between people and their computing devices, but between actual, everyday things like windows, highways, bananas, pets, appliances and more. By enabling connectivity for virtually any physical object that can potentially offer a message, the X-Internet will affect every aspect of life and business in ways that used to be the realm of fantasy — or even beyond fantasy.

Motorola is leading the way in making the X-Internet a reality. This white paper looks at the concepts, standards and technologies that are driving the X-Internet, and some of the application areas that Motorola is contributing to, now and in the coming years.

The X-Internet will transform our lives and businesses in much more powerful ways than the cell phone or even today's Internet itself.

THE X-INTERNET TODAY

- Smart parking systems can bill users for parking time automatically, ensuring compliance, reducing enforcement and maximizing revenues.
- Retail, shipping and warehousing companies are moving to RFID to track inventory and trigger billing systems. RFID eliminates the manual labor of scanning UPC codes, and adds new capabilities such as automatic reordering of stock based on what's actually on the shelves.
- When hospitals bill insurers for the use of infusion pumps and other medical equipment, they must provide insurance companies with documentation of patient information and length of time the equipment was used. Active RFID tags on the equipment can be used to track where equipment is being used throughout the hospital, automatically providing the required records.
- The U.S. Military is using active RFID to manage shipments in transit, allocate material where it's needed and ultimately to manage battlefield logistics and save lives.
- Automotive manufacturers are exploring ways to better control just-in-time delivery of parts by having the parts monitor and report on their own status. Wiring harnesses, for instance, get brittle when they're cold and can't be installed until they have warmed up. Intelligent two-way sensors on the harnesses can report their own temperature and location, enabling supply chains to automatically adjust for optimum delivery times.
- Mining companies and transportation agencies are beginning to use intelligent sensors to monitor conditions and alert authorities to hazardous conditions and needed maintenance. Sensors can be used to monitor for poisonous gases, the structural integrity of bridges and tunnels, the location of workers and so on.

Introducing the Future: The Extended Internet

Twenty years ago, it was almost unimaginable how the brick-sized cell phone device that some top-level businesspeople were using would soon change our lives. A few years later, when e-mail was introduced, it was hard to imagine all the information, entertainment, convenience and communication that today's Internet would bring. Similarly, the X-Internet can be difficult for people to "get" upon first hearing about it.

But, without a doubt, the X-Internet will transform lives and businesses in much more powerful ways than the PC or even today's Internet itself. Today's Internet connects people to people. Oftentimes it's not a direct connection, but think about it: retail sites, databases, games, content, search engines and more are all ultimately created by people, using display formats that make sense to people, with the sole purpose of serving other people. The X-Internet goes much further: It adds connectivity for physical objects, creating a wealth of new opportunities for intelligent interaction between people and things, and even between things and other things.

Like pieces of a puzzle, many of the enabling technologies and early implementations are already in place. Inexpensive radio frequency identification (RFID) tags are being placed in parts, products, access cards and more to uniquely identify each item. These passive tags are tiny, inexpensive and require no battery power. Devices designed to read these RFID tags can be placed in doorways, turnstiles, and other portals to track objects entering and leaving the area.

By adding small, inexpensive, battery-powered radios to RFID tags, it becomes possible to deploy more sophisticated tracking applications that cover a much larger area — for example, tracking people and items throughout an entire building. In active RFID systems, RFID tags broadcast their own signals rather than echoing a signal broadcast by the RFID reader. This allows deployment of fewer, simpler, and more affordable readers, while also enabling more sophisticated applications.

The next step in RFID-based technology is tags that incorporate environmental sensing, intelligence and two-way communications. These can be incorporated today in sensor networks, mesh networks and ad hoc networks for a variety of purposes. The ZigBee Alliance is working on standards for this type of networking, and standards-based products and solutions are beginning to become available.

These solutions are growing out of existing Internet, wireless and remote sensing capabilities. The X-Internet will build on these technologies with new innovations that provide ever-increasing connectivity for new kinds of applications. This revolution will soon spread from industrial and governmental implementations to enterprise applications and even the home and everyday life.

Technologies Enabling Seamless Mobility in the X-Internet World

The whole point of the X-Internet is to make every aspect of life easier, giving people and businesses full control over things and the way they interact with people, the environment and each other. Insofar as possible, that control should happen automatically — in accordance with user needs and preferences, but without requiring explicit commands.

From the end-user's point of view, the X-Internet simplifies everything. But that means all the complexity is transferred from the user to the underlying technology.

Advanced, cooperative wireless technology

The X-Internet will connect all kinds of things in all kinds of spaces. Mobility will be the norm. That means, first and foremost, that the X-Internet will depend on pervasive wireless connectivity. At the same time, different X-Internet applications will have different requirements for radio frequency, range, data rate and cost — so cooperative wireless technologies will be required to allow systems based on multiple standards to work together seamlessly.

In an X-Internet enabled home, for example, low data-rate systems such as home security, monitoring, and environmental control will share the same network that streams high-bandwidth music, video, and games to entertainment devices throughout the house. Enabling technologies for the X-Internet must automatically resolve the differences between various radio technologies and communications protocols to allow seamless interaction.

Context awareness

True seamlessness depends on the ability of devices and even inanimate objects to sense their environment, and to communicate their own presence and context to other relevant devices and objects. Depending on the application, context-aware nodes may sense:

- The technical environment, including what networks and devices are within range, what RF standards are in use, what applications and content are available and so on. This mode of awareness enables X-Internet nodes to automatically join available networks and exchange data as required by the application.
- The physical environment, including aspects such as temperature, moisture, lighting, vibration and equipment parameters. Many of these capabilities are already in use today by manufacturing, distribution and other vertical enterprises. The X-Internet will require similar capabilities to be distributed horizontallly across all kinds of objects — exponentially expanding the types of data and relationships available for processing to enable new kinds of business and personal applications.
- Human behavior, and other new categories of complex, highly integrated awareness. Devices of the future will observe user behavior and monitor the environment to seamlessly deliver the appropriate content and services. For example, the security systems of the future might be able to automatically recognize the difference between a resident and an intruder, notify the authorities, activate and control video cameras, lock rooms containing valuables and more — all without requiring the user to configure and activate the system manually.

True seamlessness requires autonomous, peer-to-peer local awareness and connection between things themselves.

Peer-to-peer awareness, self-organization and autonomous action

In addition to traditional connectivity via a higher-level infrastructure, true seamlessness requires autonomous, peer-to-peer local awareness and connection between things themselves. This peer-to-peer awareness is a new paradigm, beyond the remote sensing and control that is rapidly becoming familiar today.

An important requirement for peer-to-peer awareness is the ability of networks to self-organize and self-maintain. As devices and objects of all kinds become part of the global X-Internet, the number of potential nodes will grow by orders of magnitude compared to today's Internet. With billions of nodes coming online, many of them mobile, networked things will need the ability to sense available communication and control channels, automatically joining the appropriate subnets and applications, without human intervention.

Nodes also need the ability to intelligently establish communications with other nodes using the minimal number of "hops." This could involve a relatively limited network, such as wireless peer-to-peer hopping across the sprinkler controllers in your yard. Or it could involve a global network in which a message takes a wireless hop or two to a nearby access point, then travels to another access point halfway around the world via the wired Internet, and finally takes another wireless hop to reach the target device.

Peer-to-peer sensing and interaction must also be complemented by traditional, hierarchical control, when appropriate. Consider the example of an X-Internet traffic control system (Figure 1). Peer-to-peer awareness and autonomous action allow the system to instantly coordinate signals for optimum traffic flow, without requiring human intervention. At the same time, hierarchical control enables the system to send information back to traffic engineers that helps them diagnose chronic traffic problems and plan future road projects accordingly. Depending on the application, the X-Internet will require a flexible mix of both autonomous and human-driven control.

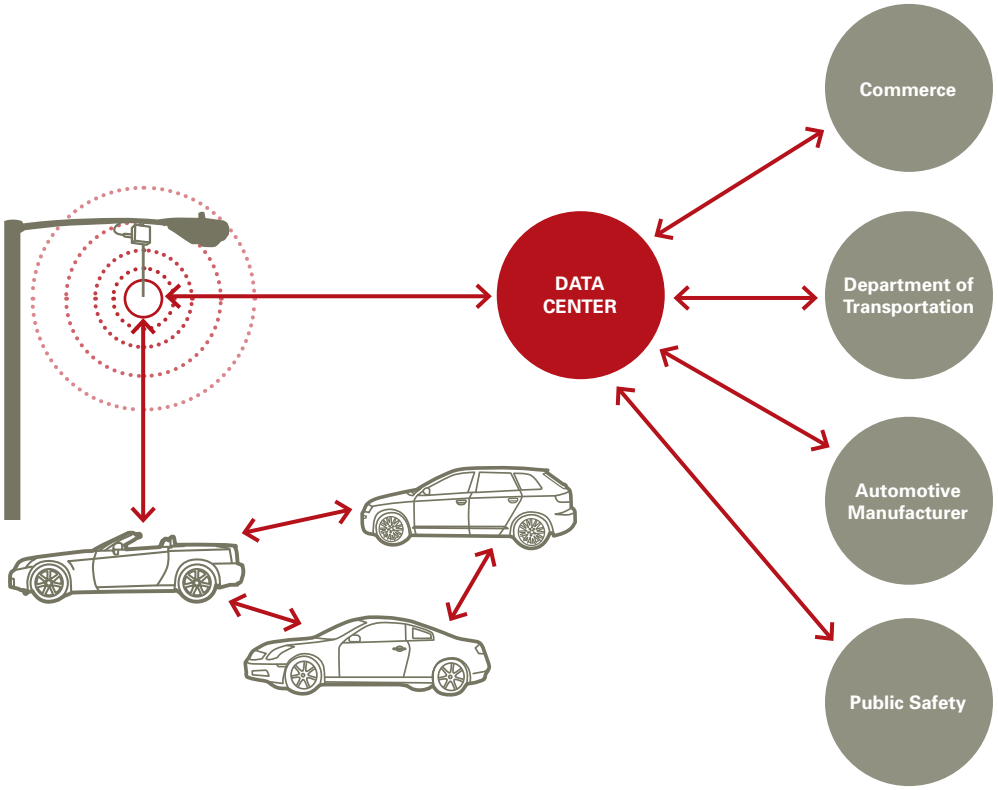

Figure 1. An X-Internet vehicle information and traffic control system will be able to provide sensing information that can improve traffic flow and safety on our roadways, while also providing information to OEMs and businesses that will help enhance customer relationships and maintain customer loyalty.

Energy efficiency and self-generation of power

New sensing, control and radio technologies need the ability to operate in the field for very long times while consuming very little power — or even scavenging all the power they need from the environment. Many X-Internet devices will still use battery or line power, but new types of nodes will be deployed by the thousands — often in extremely small packages and difficult locations — making it difficult or impossible to change batteries.

New energy-scavenging technologies will enable nodes to operate indefinitely without batteries. An emerging generation of photovoltaic technology will allow so-called "solar" cells to operate using the ambient light in your house — and the cells will be small enough to incorporate invisibly in windows and even paint. Other technologies will enable nodes to scavenge energy from thermal energy, kinetic motion and other environmental sources.

As an example, the HVAC system of the future might have X-Internet sensors installed at various locations on your house ducting. These sensors could extract energy from the vibrational motion of the ducts themselves, using that energy to monitor temperature, humidity and air quality. The system would keep conditions ideal without requiring you to constantly fiddle with the thermostat, and it would even alert you when thresholds are exceeded indicating that it's time to change air filters or perform other maintenance.

New form factors

Finally, new form factors will be required to enable nodes that can be deployed in virtually any environment. Today's wireless security sensors that are typically placed adjacent to window and door frames will, in the future, be part of the frame itself. Sensors that can survive caustic environments and extreme temperatures will enable new kinds of applications for industrial control, agriculture, traffic management, homeland security, climate modeling and more.

Small, affordable sensors will be developed that can be embedded in commodity products — similar to RFID tags, but with additional capabilities that include intelligent sensing, control and connectivity. Sensors that can be injected subcutaneously or even ingested orally by animals and people will enable new methods of healthcare monitoring, emergency response and other similar applications.

The X-Internet is also a natural environment for microelectromechanical systems (MEMS) and nanotechnology to flourish and reach their full promise. This frontier of science and technology focuses on the automatic assembly of extremely small "smart" particles and devices — measuring from a millimeter to a millionth of a millimeter or even smaller in size. At these scales, objects can have very different physical properties than larger objects, offering exciting potential for new applications in materials engineering, healthcare, geophysics, computing, telecommunications, energy and many other fields.

For example, microelectromechanical sensors with integrated wireless communications may one day enable "smartdust" networks. These networks would be analogous to traditional sensor networks, but with sensors that are microscopic in scale and affordably deployable by the millions. At home, these technologies might allow builders to incorporate environmental-control, security and other types of networks invisibly within building materials. In the military, smartdust might be used to invisibly perform enemy surveillance, track troop movements, or detect radioactivity and poisonous gas. And the potential applications in other fields are virtually unlimited.

Motorola is helping to design and promote the adoption of standards at all technical levels to enable X-Internet interoperability, creating a level playing field for vendors and consumers alike.

The X-Internet Architecture

Motorola believes that the success of the X-Internet, like today's Internet, will depend on the development and widespread adoption of several architectural elements, including global standards, built-in intelligence, advanced data interpretation, exception-based control, security and privacy and IPv6 addressing (Figure 2). Motorola is providing R&D and industry leadership in each of these areas.

Standards

Open architectures based on global standards will be required for X-Internet devices from different vendors — designed for different purposes — to interoperate seamlessly across multiple bands, devices and countries. Proprietary implementations that don't "play well together" in an open fashion will be doomed to failure. Motorola is helping to design and promote the adoption of standards at all technical levels to enable X-Internet interoperability, creating a level playing field for vendors and consumers alike.

Built-in intelligence

Because the X-Internet will be based on highly distributed computing across vast numbers of nodes, Motorola is building intelligence into devices to facilitate rapid deployment, self-management and easy reconfiguration. This intelligence is required at all levels: in processor architectures, routing technologies, programming languages, management protocols and applications.

For example, the home of the future could contain thousands of X-Internet nodes. Users will require an easy way to configure these nodes, and to reconfigure them as their needs change or when the house sells. The elements of the X-Internet and the ways they interact will be incredibly complex, involving multiple layers of intelligence — but Motorola is working to ensure that this complexity results in incredibly simple end-user interaction.

Advanced data interpretation

The X-Internet will require new models for data distribution and aggregation, data filtering and fusion, intelligence gathering and knowledge creation. With all the sensor data and control capabilities that will be available, applications will need the ability to extract meaningful information from the wealth of available data in order to come to new conclusions about the world and manage systems more efficiently. Motorola is helping define and build the high-level technical framework to allow diverse systems to share data, interpret it within context and use it in new ways.

Exception-based control

Ultimately, all the new knowledge gathered and synthesized by X-Internet applications must be put to use in ways that support a seamless experience, managing most of your life automatically while you do the rest by means of exception-based control. Human interaction with systems should be at the highest level possible, while the systems themselves take care of all the detail. Systems should make intelligent observations about the user's behavior and surroundings, so that even exception-based control becomes less necessary over time. Motorola is the industry pioneer in devices that are designed to adapt to the user, rather than vice versa.

MOTOROLA LEADERSHIP

The X-Internet will depend on innovation across a wide range of technical fields. Motorola is already on the vanguard, creating X-Internet foundations that include:

- **Leadership in the 802.15 Forum.** The 802.15 family of wireless standards will enable wireless peer-to-peer and personal-area networking using lightweight, low-power, low-cost radios.
- **Leadership in the ZigBee Alliance.** Motorola is working with other technology companies to create global standards for cost-effective, low-power, wirelessly networked monitoring and control products.
- **neuRFon™ solutions.** Motorola's research and development into large-scale networking of relatively simple wireless nodes — much like the networking of nerve cells within the body — has led to proven solutions that anticipate the X-Internet.
- **Proof-of-concept trials.** Motorola has successfully deployed first-generation X-Internet solutions in cooperation with the National Institute of Standards and Technology, Defense Advanced Research Projects Agency, Department of Homeland Security, government of South Korea and other organizations.

Security and privacy

With so much information available on a global network — including information about personal preferences, affiliations, location and so on — protecting users' security and privacy will be essential. The X-Internet will require sophisticated new security technologies that leave consumers and companies in full control of what information is shared and when. Motorola's strategy is to create a wireless security foundation that defends X-Internet communications in depth and end-to-end.

Motorola believes that security and privacy controls must operate on two levels — enabling network infrastructure to be shared while preventing unauthorized users from controlling applications or accessing protected information. In a corporate environment, for example, the fire detection and suppression system might share network bandwidth with the building-control systems, computer management systems and even the copier monitoring and maintenance systems.

IPv6 addressing

The X-Internet will eventually incorporate billions, perhaps trillions, of new network nodes. IPv4 is the current packet-switching protocol that provides a unique address for every attached device. It supports 4.3 billion IP addresses, which is less than one address for every person on the planet. As it becomes the norm for people to own multiple IP-enabled devices, it's clear that IPv4 will soon become inadequate to handle the existing Internet, let alone the X-Internet.

IPv6 is already making inroads on the Internet. It supports 128-bit addressing, potentially providing unique addresses for as many as 3.4×10^{38} nodes. That's more than one address for every atom in the earth's continents and oceans. Although there's no need to address individual atoms, IPv6 will allow addresses to be allocated in large blocks to avoid fragmentation, keep routing tables manageable, and simplify administration. Widespread adoption of IPv6 will be essential for complete penetration of X-Internet technology. Motorola is a front-runner in the introduction of IPv6 along with IPv4 compatibility across all product categories.

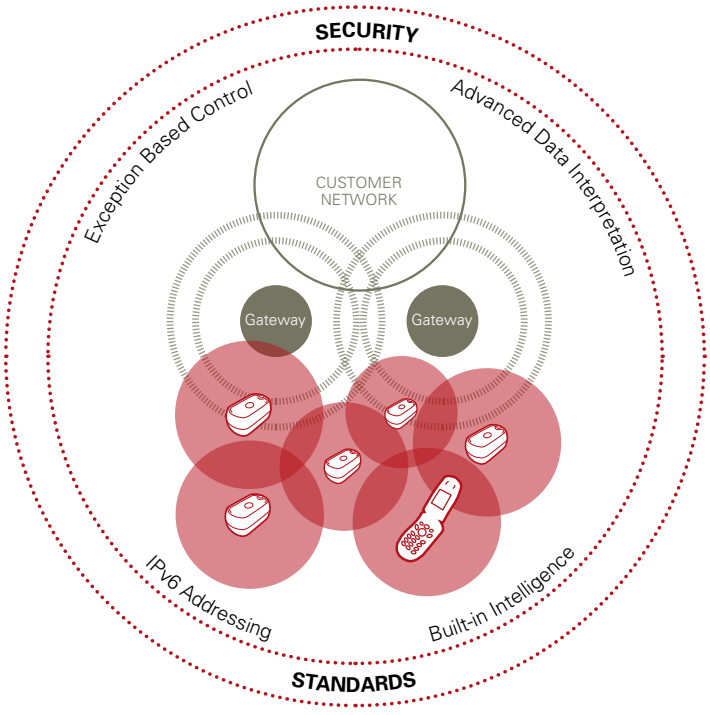

Figure 2. The ability for fixed, mobile and handset devices – or nodes – to communicate depends on the development and adoption of several architectural elements, including global standards, built-in intelligence, advanced data interpretation, exception-based control, security and privacy and IPv6 addressing.

Enabling technologies for the X-Internet are already transforming government and industry, offering a preview of the kinds of capabilities that will one day be linked across all kinds of usage models.

The Opportunities

Building blocks of X-Internet technology are already making inroads in:

- **Product lifecycle management.** Companies are already using RFID tags at the pallet and even the product level to streamline the supply chain. In the X-Internet world, smarter tracking capabilities will make products more useful and easier to maintain throughout their lifecycle. For example, if your plasma TV develops a problem the X-Internet could automatically notify the manufacturer about the problem, track an authorized person as he enters your house to pick up the TV and track the unit as it makes its way to the service center and back to your home.
- **Transportation.** Smart signals and sensors are already at work in many metropolitan areas, sending data and images back to a control center where people can supervise signal timing, message displays, and other devices to improve traffic flow. In the X-Internet world, these systems will be able to provide real-time crew status, vehicle density information in work areas and possible obstacles in a crew's path to both the control center and the dispatched crew — automatically and in near-real time. And the network will be able to communicate directly with drivers wherever they are, warning of dangers, providing estimated travel times suggesting the fastest possible routes given current conditions.
- **Agriculture.** Many farmers are already using remote sensing and control to manage irrigation. In the future, X-Internet sensors will form wide area networks across the entire farm, giving visibility and fine-tuned control over the entire operation. Water rates will be determined by actual soil moisture in each plot, weeds will be monitored and controlled with precisely the right amount of pesticides, fertilizing and harvesting schedules will be determined by actual leaf color and temperature and so on.
- **Safety.** Police, firefighters, and other first responders are rapidly adopting mesh technology that allows them to instantly create peer-to-peer voice and data networks at the site of an incident. The X-Internet will allow these networks to be extended to incorporate building sensors, traffic controls, security cameras, vehicles, personal location and panic devices, public safety databases, and more — providing all the information public safety officials need, instantly and seamlessly.

Imagine the Possibilities

These are just a few examples of what the X-Internet could bring in the foreseeable future. The reality will likely become even more amazing as the X-Internet world evolves. And Motorola will be at the center of it all.

The X-Internet is one component of Motorola's Seamless Mobility vision, and we're working day by day to make that vision a reality. Follow the latest developments at Motorola as the X-Internet emerges and ultimately transforms the world. For more information, visit www.motorola.com/technology.

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