Wireless solutions for automation requirements

Carlos Cardeira[1], Armando W. Colombo[2], Ronald Schoop[2]

[1]IDMEC, Instituto Superior Técnico, Portugal

[2]Schneider Electric GmbH, Germany

Abstract

Wireless technologies are being more and more used in automation, not only because the installation costs are much lower, but also the true self-reconfiguration of a system without any rewiring becomes possible as ever did before. Together with other technologies like service oriented architectures and the use of agent technology, wireless at the physical level play an important role towards flexible and self-reconfiguring systems. To try to have a clearer view about how wireless technologies are suitable or not for automation purposes, we first enumerate the communication requirements of several typical applications. We group the applications into classes and then we present what subsets of wireless technologies do cope with the specific requirements of each class of automation problems. Moreover we present self-powering issues and new opportunities for wireless networks, like location aware systems.

Keywords

Wireless communications, automation, location awareness, self-powering

1 INTRODUCTION

Currently, a large amount of the total cost of a manufacturing plant over its lifetime is spent on installation, setup and reconfiguration. If a plant is subject to changes in its process flow or changes due to the introduction of new or replacement of noncompetitive equipment that is provided by different makers, then the downtime and lifetime costs rise considerably [1].

Some of the main obstacles to fast reconfiguration is the inflexible wired communication infrastructure and the difficulty to port existing application software to new configurations [1]. The problem of software reconfiguration is being addressed by several on going works namely by the use of service oriented architectures. The problem of the inflexible communication infrastructure can be largely eased by the use of wireless technologies. In this paper we address how wireless communications technologies, as a way to ease the problem of physical inflexible communication infrastructures, are (or aren't) suitable to deal with current automation requirements.

1.1 Motivations for wireless

There are several possible motivations for wireless use in automation.

Application specific

Sometimes the use of wireless is mandatory. This is the case when the mobility of some devices is required, as for instance, in Automatic Guided Vehicles. It is also the case for applications where chemicals, vibrations or moving parts could damage cabling. In these cases wireless communications are almost a must for the application.

Economical advantages

In some cases there is not and absolute need for wireless but the costs of wiring are prohibitive, as it would be the case of reading a small number of sensors in a large geographical area. In these cases, wireless is not a must but it presents economical advantages. To a certain extend, these are somewhat the same economical advantages that, in the past, were used to justify the use of fieldbus instead of point-to-point connections, but now with a more drastic approach (zero cabling costs).

Flexibility

On other cases, it is not just the economical advantage that is sought. The question is that, with wireless technologies, not only the installation costs are much lower, but also the true self-reconfiguration of a system without any rewiring becomes possible as ever did before [1], [10]. Together with other technologies like Service Oriented Architectures, Web services and the use of agent technology, wireless at the physical level play an important role towards flexible and self-reconfiguring systems.

As with every new technology, the use of wireless presents advantages and drawbacks. Bellow we present a discussion of both.

1.2 Wireless advantages

Main advantages of wireless are related to the reduction of cabling cost and the incresaed flexibility.

Reduced wiring communication

Without wires, cost intensive wiring plans become obsolete. Labor-intensive cable installation costs will be dramatically reduced and there will be no more need for wiring maintenance tasks.

Reduced power cabling costs

The freedom to place wireless sensors anywhere in the factory plant or a building gets limited if those devices have still to be connected to a main power source. So further advances would be achieved by obviating the need of power cables. In the field of sensors, using low power semiconductor technologies, power cabling can be obviated if the sensors use internal batteries or harvest the energy from the environment (see section 7- Self Power Requirements and solutions)

Enhanced reconfigurability

The system reconfigurability is highly enhanced because with wireless we do not have the limitations of low flexible wired systems. Using the correct software architectures approaches that are out of the scope of this paper, a new device that comes into the range of a wireless network can offer its services to the network and get new tasks allocated to it. This would be done automatically and transparently, not requiring a single physical connection.

1.3 Wireless handicaps

In spite of the economical and structural advantages, some skepticism exists towards the use of wireless in industrial plants, especially in real-time systems.

Path loss

Wireless communications are subject to much more path loss. Depending on the type of antennas used, isotropic or with the gain increased in some directions, the signal strength decreases with distance exponentially. The strength loss exponent varies also with the environment conditions but is typically between two and three [11].

No collision detection

Wireless communications do not support full duplex communications, because when a device transmits, it is not able to receive on the same channels. Moreover, when a station is transmitting, its signal power exceeds any receiving signal so there is now way to detect collisions. Without detecting collisions, CSMA/CD protocols cannot be used. The solution relies on CSMA protocols and collisions may exist but they are not detectable.

Hidden terminal problem

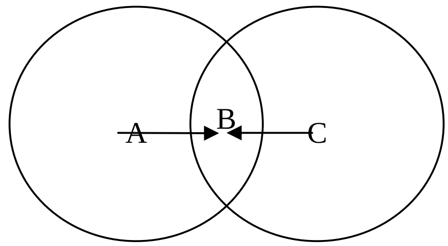

Figure 1: The hidden terminal problem

Even pure CSMA methods have the problem of the hidden terminal [4]. This problem is illustrated in figure 1. Stations A and C are out of each range but station B is in the range of both. If station A transmits to station B, station C is not aware of this communication because it is out of range. It senses the medium free and may start transmitting provoking destructive interference in station B. Nowadays, for instance in IEEE 801.11 [5], the solution found for the hidden terminal is a RTS/CTS protocol. In this scheme, station A will not start its communication with station B without sending first a RTS short packet. Station B will answer with a CTS short packet. Upon reception of the CTS packet station A resumes transmission. The advantage is that any other station receiving an RTS or CTS packet not addressed to it will not start a transmission for the time indicated in the RTS and CTC packets.

Multipath fading

The wireless communications are prone to reflection and diffraction. In the destination station many copies of the original signal may be received. As they've followed different paths the interference is usually destructive [11]. Solution to this problem can be achieved by using the so-called spatial diversity. Receiving diversity exploits the use of multiple directional antennas in the receptor. Transmit diversity exploits several directional antennas in the transmitter and the retransmitted signal is sent thought different antennas [6]. If, for reasons of cost, the stations do not have multiple antennas the so-called cooperative diversity scheme uses other stations to help retransmiting the packets on behalf on the transmitting station [11][7].

Higher overheads

The physical layer overheads are higher than wired solutions because of extra training sequences necessary to establish communication. The probability of getting channel errors is higher as wireless communications waves are also subject to multipath fading [11]. This problem is even more important for communications of short messages as it is often the case for fieldbus systems.

Security

There are security issues as wireless waves are easily detected by any receptor in the range for illicit eavesdropping. However, message data encryption is enough secure today to deal effectively with this problem.

Safety

In spite of strict regulations about electromagnetic interference, in an industrial environment, strong motors, electrical discharges usually affect wireless communications too. The are issues in safety, because wireless networks can be jammed unintentionally as by other equipment or by intentional criminal acts. The wireless medium is an open medium and it is easy for an attacker to insert malicious packets, or to simply jam the medium.

For critical applications and low range wireless communications, it might be necessary to operate the wireless devices inside a Faraday cage.

2 Application requirements

Automation is a large domain and the requirements vary a lot in several automation fields. Consider, for instance, these two examples:

- A Remote Terminal Unit that monitors a few variables and transmits them, about every minute, to a remot long-distance control station;
- A 50 cm range wireless network connecting the controler, encoders and PWM generators of a closed loop control of an high and critically stable speed AC motor.

The wireless communication requirements for the systems shown above will naturally be highly different.

Wireless technologies are available and wireless surveys are already available [10][11], but their ability to fulfill the needs of an automation system is largely dependent of the application requirements.

To try to have a clearer view on how are wireless technologies suitable, or not, for automation purposes it becomes necessary to enumerate the communication requirements of several typical applications, group them in classes and then see what subsets of technologies do cope with the specific requirements of each class.

Following this analysis we got the following more or less representative application classes:

2.1 Very Loosely coupled

In this class we consider applications where wireless is a need mainly because of the large distances to cover when accessing remote sites. Typically these are remote terminal units that are used to monitor the state of remote sites and send data and alarms to the long distance control room. Application examples are the monitoring of the state of transmissions antennas [5], remote water supply pumps, coast lighthouse beacons, which are usually autonomous systems that require periodic maintenance. Using wireless technologies, some important events are sent to a central control station, like changes in temperatures, power consumption, power factor, etc. As the cost of sending maintenance teams is high, wireless technologies are important to reduce the number of interventions and to provide more efficient and predictive maintenance interventions.

2.2 Loosely Coupled

This class corresponds to applications where a large amount of devices, typical sensor devices, are spread for an area to monitor system variables. Typically, heating, ventilation and air conditioning systems of building automation belong to this class [9]. The application usually involves small amounts of data mainly composed of short messages and the update rate is also low. The main advantage of wireless in this system is cable reduction costs and flexibility on positioning or repositioning the wireless sensors. Low power consumption is an important feature because these sensors should be able to operate autonomously with a small battery for 3-5 years [9]. Individual cost plays an important role because these networks are usually composed of an extremely high number of devices.

2.3 Normally Coupled

This class corresponds to applications where the required bandwidth is higher than the loosely coupled class and the special lower power consumption is no more a requirement. Downloading the new code to a CNC machine is an example of such application. The required performance is higher because the amounts of data necessary to transmit are larger. There are no strict real-time requirements and the range is typically 10-100m.

2.4 Closely coupled

This class corresponds to applications where a device communicates with other devices within a small range, typically up to 10 meters to exchange data with soft timing constraints. In this class we may find applications where a PDA equipped with a supervision system monitors and diagnosis the state of a given equipment, or set the values of a motor controller.

2.5 Tightly coupled

This class corresponds to applications where the distances to cover are short but the necessary bandwidth is high and must be much reliable. In this class we consider networks that run typically inside a machine. For instance, inside a CNC machine or a mobile robot there are several motor control loops, which may require short cycle times and low jitter. The range to cover is small, typically bellow one meter. To avoid external interference, the equipment containing the wireless devices might operate inside a Faraday cage.

3 Available Technologies

We briefly present now the most representative available technologies. For details see [10][11].

3.1 WiMAX

WiMAX is a Wireless WAN being discussed in the IEEE 801.16 group. WiMax has a long transmission range (up to 50 km) at 75 Mbps rate per channel, but can also be used for last mile broadband communications. Combining multiple IEEE 802.16 channels for a single transmission it might provide bandwidths up to 350 Mbps. Originally the 10 to 66 GHz band was used but under the IEEE 801.16a standard it will also operate on the licensed and unlicensed 2 to 11 GHz band. The interest on these lower bands is that the signals can easier penetrate non-metallic obstacles and most walls, enabling communications out of line of sight [14].

3.2 Wi-Fi

Wi-Fi standards are based on the IEEE 802.11 specifications. Most common implementations support up to 11 Mbps (802.11b) or 54 Mbps (802.11g) with a typical indoor range of 30 m indoor or 90 m outdoor range. Wi-Fi is a very popular solution and the equipment costs are low. They use the 2.4 Ghz unlicensed band so there can be a lot of interference among these devices as well as from satellites, microwave ovens and high-end wireless phones. The 5 GHz band of 802.11a deals with much less inference [18], however it incurs in more difficulty to go through walls, making its range shorter. It is expected that the standard 802.11n will soon be available which goal is to increase the rate and range. The standard 802.11e aims to implement the quality of service functionality and provide deterministic media access.

3.3 Bluetooth

Bluetooth is a set of protocols with the physical layer based on IEEE 802.15.1 standard. Bluetooth 2.0 supports data rates up to 2.1 Mbps. Most common implementations are lower power ones which range can be up to 1 m or 10 m depending on the power class. They also operate in the 2.4 Ghz unlicensed band. Bluetooth devices require much less power than Wi-Fi, but the area covered and data rates are also much lower.The limited range, which one could consider a drawback, is actually more an advantage than a drawback because the same frequency can be reused in closer locations. Bluetooth is a mature technology, the stack can be implemented in a small microcontroler because no OS is necessary. The specification is open but manufacturers have to pass by non-free qualification procedure.

3.4 ZigBee

Zigbee is a set of protocols with the physical layer based on IEEE 802.15.4 standard. It operates in several frequencies including the 2.4 GHz band used by most Wi-Fi and Bluetooth devices, it presents a comparable or slightly higher range (10-100 metres), a lower data rate (20-250 Kbps). The main advantages of ZigBee are lower power consumption and network self reconfiguration. ZigBee devices are able to 'sleep' most of the time. The power consumption is reduced, making it possible to have devices that operate with a single battery for years [12]. The standard provides star or meshed networks. In the latter case, it allows the coverage area to be extended when new nodes are added. The protocol is designed for reducing the power consumption as nodes are switched on and off according to the possibility of being addressed or not.

ZigBee is an emerging technology and it is not as mature as Wi-Fi and Bluetooth. As ZigBee fulfils the requirements of low power and low cost, it is a promising technology for sensor networks.

3.5 UWB

Ultra-Wideband is a technology where the communication is send by short-pulse electromagnetic waves, instead of the usual modulation of sinewave carriers [13]. It is claimed that UWB might achieve rates up to 500 Mbps in a 2 m range (or 110 Mbps in a 10 m range) operating in the same bands as other communication systems without significant interference. The occupied band is very large (500 Mhz or 20% of the centre frequency) but the hardware will consume just a few mW of power.

It is expected that the future wireless USB will be based in UWB. Currently, there are two competing proposals: Cord-Free USB from Freescale and Certified Wireless USB from the WiMedia Alliance. However the standard, which was discussed in IEEE 802.15.3a, is still not known because after two and a half years of discussions, in January 2006, the IEEE standards group finally voted to disband. Both UWB technologies will have to fight it out in the marketplace until consumers will declare a winner [15].

3.6 NFC

Near Field Communication (NFC) is a technology where a emitter provides a magnetic field and the receiver answers by modulating this field. The speeds are limited (106, 212 or 424 Kbps). The maximum operating distance is 1.5 - 2 m, however, only small distances 0-20 cm are usually considered.

3.7 RFID

Radio Frequency Identification (RFID) is technology for a wireless transmission of device identification. Their main goal is to replace the bar code labels. Passive RFID tags are powered by the microwave signal they receive through the antenna. They answer with a sequence of bits that defines its identification [17]. Why are they called here, in the scope of this paper? Because if instead of just identification, RFID tags read the state of some attached sensors (temperature or a MEMS accelerator for instance) and have internal active power (for instance, harvesting the energy from the environment [10]) their use in automation may largely exceed device identification.

3.8 GSM 2G and 3G

The usual telecommunication GSM services are evolving and providing larger coverage and higher rates with GPRS or UMTS. The main inconvenient is that these technologies require an infrastructure of a service provider. They provide a quality of service that cannot be always enough for wireless coupled automation.

However, in remote installations, like water supply systems, remote RF antennas, windmills, solar power plants, where the cost of local maintenance operations is high, cost savings can be done using the GSM based networks. Data from the remote station can be packed and sent through the GSM network. The generated traffic is small (order of a few bytes a second or even a minute) and there is no big issue if connection is momentarily lost. In this case, these networks are very useful providing a strong reduction on the number of costly local maintenance visits.

3.9 Others

Some other technologies where not considered, either because they are still immature or because their use in automation is not yet established. WiBro (Wireless Broadband) is primarily based in South Korea and aims to provide a high data rate wireless internet access with PSS (Personal Subscriber Station) for the stationary or mobile stations. It is too soon to state about the success of this technology. DECT is a well-known technology for wireless phones and some works have been carried out for their use on automation. IrDA is an infrared physical layer protocol that had a very promising start and gathered some popularity, but its main drawback is that it requires unobstructed line-of-sight [18] and point within a specific angle range.

4 Wireless solutions for Automation

As we’ve shown before, there are a lot of available technologies and their use for automation depends on the application requirements.

Figure 2 shows a qualitative map about the use of these technologies according to the defined application classes and the range to cover. In this figure, we may see that there are not much solutions for tightly coupled systems. ZigBee is not a candidate because of its low bandwidth. In ZigBee, low power consumption is mainly achieved by the possibility of putting the nodes in a “sleep” state and this is incompatible with the high activity of tightly coupled nodes. NFC is a good candidate but the performances are limited. UWB and Bluetooth are good candidates, especially UWB because of its higher (promised) performances. However Bluetooth is well established actual standard whereas UWB is a promising technology for the future.

RFID tags, if used not only for identification but also to transmit data from integrated MEMS sensors might be a solution for closely or normally coupled systems. They are not suitable for tightly closed systems because of the high response time.

ZigBee is more suited to communications where short amounts of data are sent only during specific periods of time. This was a drawback for their used in tightly coupled systems but they are a good solution for loosely coupled and normally coupled systems.

Wi-Fi occupies the middle range of the panorama. Further developments of Wi-Fi, especially 802.11n and 802.11e may even improve Wi-Fi features for closely and normally coupled systems.

For very loosely coupled systems, the proprietary solutions seem less interesting because of the costs of developing a specific installation and the difficulty to access to bands other than the public domain bands. To rely on the services of a telecommunications provider, even if not always desirable, is still the best solution to access to long distance remote sites. UMTS or GPRS may have some loss and be momentarily unavailable but their range is almost unlimited.

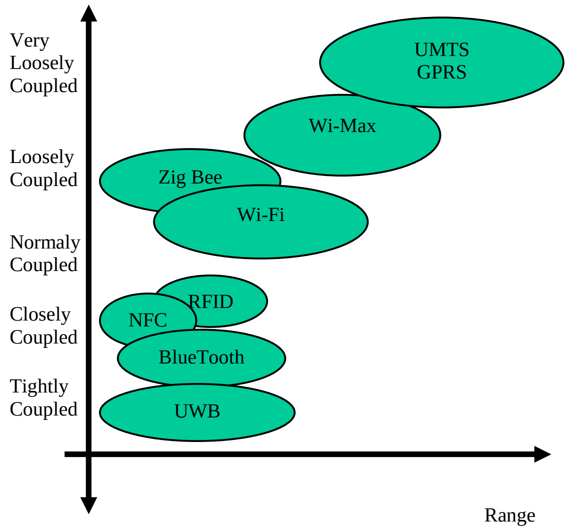

Figure 2: Panorama of wireless solutions

5 Coexistance of wireless solutions

In many automation applications many of these solutions must coexist.

For example, mobile robotic applications that have visual feedback predominantly use Wi-Fi because they need a high bandwidth for real-time video transfers. However, for transmitting the data of the robot sensors and alarms the demands in bandwidth are much lesser but the reliability must be higher and Bluetooth or ZigBee could be preferable for this traffic.

The same system may present requirements of different classes and require different type of networks to fulfill its requirements. For instance, let us suppose that a motor motion controller is composed by some separated units. The units are embedded in the sensors and actuators of the motor that it controls. Suppose that these parts are wirelessly interconnected. Such a physically distributed motion controller, if wirelessly distributed among the parts of a motor, has different requirements when performing the position control loop (30 Hz for instance), the velocity control loop (2 kHz for instance) and the current control loop (10 kHz for instance).

For Bluetooth, ZigBee and Wi-Fi, as they use CSMA they should, in theory, not have destructive interference, but in practice they actually do. Important studies are being made about the coexistence of the different protocols, because they often share the same spectrum band [11].

6 Location awareness

Wireless communications present another, somewhat unexpected, advantage: recent developments prove that it is possible to know the position of a device by measuring and correlating the signal parameters when they arrive to the wireless access points.

Wireless location awareness emerged for safety reasons in cellular phones. According to the existing FCC laws that are being adopted by many countries, mobile phone providers have to deliver the precise location of the emergency calls, within 100 m of its actual position for at least 67% of the calls. The solution of installing a GPS receiver in each device has a lot of drawbacks (cost, outdoor only, need to modify the devices). One of the solutions found is based in measuring the time delays and angles of the signal emitted by the device and fusion all the data to have an estimation of the device location [16]. This approach has the strong advantage of requiring no modifications on the existing cellular phones. In Wi-Fi networks, a similar approach is used to provide more location of Wi-Fi devices [21].

With the availability of a location aware system for mobile devices several applications and new services are being proposed. In [16], several applications are considered like mobile advertising, assert tracking, fleet management, security and location sensitive billing.

It seems that not much attention has been dedicated to accelerometers or other devices for incremental position measuring. There are Microelectromechanical Systems (MEMS) that implement accelerometers that could easy fit inside a sensor. It is well-known that a location awareness system based in these accelerometers would be subject to accumulative errors, but they have the advantage of being very resistant to external interference. Absolute location measuring technology, like GPS or network based location, are subject to sometimes frequent interruption of the service, specially in indoors environment. As it has been widely used in robotics, the fusion of both signals (with Kalman filters, for instance), would be a good mixed solution. The incremental location system based on the MEMS accelerator would provide location when the absolute position signal is not available (if just for a small time). Conversely, the absolute position system would correct the accumulative deviation errors of incremental location system based on the MEMS accelerator.

Among these new applications, for industrial purposes, we draw the attention to the following areas where location awareness can have a strong positive impact.

6.1 AGV Guidance

The location awareness of devices is important for Automatic Guided Vehicles (AGV). Usually AGV guidance and control systems compute the AGV position by making the fusion of data from the wheels incremental encoders (which are prone to accumulate errors) with the data of an absolute position. The absolute position can be given from triangulation or the passage by referenced places identified by sensors [20]. Recent developments turn the use of wireless into an easier solution for the AGV to recognise its absolute position.

6.2 Maintenance

For maintenance operations it is very convenient for the operator to carry with him a wireless palm device or similar equipment that would guide him directly to the equipment that needs assistance. It becomes not surprising that also in the industrial levels the importance of pal devices grows, namely as HMI devices to remotely monitor one process or to allow managers to have access to the enterprise ERP for remotely following the activity of the plant.

There are several examples where their use is increasing. In hospitals or health care centres, while visiting patients, doctors could feed the corresponding patient data (diet regimen, medication, etc) on PDA which in turn could be connected with the corporate ERP. In restaurants, they are increasingly being used as a device to help servers taking note of customer orders. In logistics and stock warehouses, PDAs could be used to take notes of the existing inventory.

In general, service and maintenance operations require mobility and PDAs provide the necessary wireless lightweight and attractive device for operators. With these devices operators can feed data to the system and it also becomes possible to use the PDA to guide the operator to a specific sensor or actuator taking into account the new possibilities of location awareness systems. The operator would be guided to the specific sensor or actuator to check it or perform any operation maintenance on it.

6.3 Tracking

Using wireless localisation technology to track products and materials in their different phases would provide more efficient management and tracking of unfinished parts. A quasi-total integration could be achieved if a similar development is made to identify the location of RFID tags [24]. Low cost active RFID cards, probably powered by energy harvesters with a location awareness system would be important for the management of a manufacturing site.

6.4 Safety - People location

Even people location in a covered area can be achieved with precision and commercial systems are already available, like the Ekahau Wi-Fi tag [21].

6.5 Games and entertainment

There is a last development in the gaming industry, called mobile gaming. These games are played with a mobile device such as a cellphone or a PDA, and use GPS technology to transform the real world into a virtual arena. Plans are underway to develop more narrative-based games, that would allow players to explore a fantasy world and solve intricate puzzles [19].

The reference to these games in the context of this article is due to the probable increase of the consumption of location based devices and provide much more opportunities for new location based services. In the actual context the location is sent by GPS which is mostly limited to outdoors usage. But we might expect that recent developments on network-based wireless solutions [22] might be interesting for these applications.

7 Self Power Requirements and solutions

Wireless devices at the sensor/actuator level and their power autonomy are closely related. The freedom to place wireless sensors anywhere in the factory plant or a building gets limited if those devices have to be connected to a main power source. Although power is generally available in the plants, it is often not provided at the precise location for the sensor placement [23].

Technologies that increase power autonomy involve reducing the power consumption of the devices and, on the other, finding alternatives to power the sensors.

The main possibilities for power sources are:

7.1 Batteries.

Battery operated devices seems a natural solution, if power consumption of the device allows a 3-5 year battery lifetime. This solution is sometimes used in temperature sensors located along one building to reduce the costs of heating, ventilation and air-conditioning systems [23].

7.2 Microwave

This is the solution used by RFID. The power needed to operate the sensor is taken from the power of the electromagnetic communication waves [24].

7.3 Energy harvesters

This is an interesting solution. In this category we consider devices that obviate the need for a battery by exploring the energy present on the environment. These devices convert some form of energy present in the environment in electrical power they need to operate. This can be done, for instance, by using coils and magnets to retrieve energy from mechanical movements as in motors, pumps or fans, by using piezoelectric materials that generate power when mechanically strained or by using thermocouples when a temperature differential is available [9], [25].

8 Conclusions

We presented some of the most common and under study wireless technologies and we showed how they are more or less suitable to deal with current automation requirements. The automation requirements where organized into classes according to several criteria like bandwidth, maximum latency, range, safety, security and jitter. For very loosely coupled and long range systems solutions like UMTS or GPRS are in better position to fit the requirements. For the intermediate level solutions like Wi-Fi, Bluetooth or ZigBee do fit the requirements but problems do exist when using those networks in the same area as they share the same frequency spectrum. For tightly coupled systems, the panorama of solutions is much narrower and probably just UWB might be in position to handle the requirements of this class.

The freedom to place wireless sensors anywhere in the factory plant or a building gets limited if those devices have to be connected to a main power source. So, new solutions are also being developed for self-powering wireless devices, sometimes relying on energy harvesters that gather the energy from its environment.

In spite of some initial skepticism, wireless communications are imposing themselves as a complement for wired communications. New interesting technologies are being provided, like location awareness, which might provide new services going from the game industry or, more specifically, to guide a maintenance team to specific points of an automation plant. The location awareness of a wireless device is a new feature of these devices. This feature may have strong impact on services where the physical location of the device is important, like tracking, logistics, security or maintenance.

Besides automation there are plenty of new applications for wireless technologies. Maybe the laptops will, in future, be composed of various wireless low range highly coupled self-powered devices. When that day will arrive, change the processor, increase the disk or memory capacities as well as adding every sort of peripherals will be as easy as just throwing them inside the laptop box. Questions like “would you borrow me your faster CPU just for a while? I’m short of memory could you borrow me some? Would you borrow me your hard disk?” seem very strange today but may become normal in a near future.

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Carlos Cardeira (Prof., 44) was born in Quinjenje, Angola, and received the Engineering and Master of Science degrees in 1986 and 1991, in Electrical Engineering from Instituto Superior Técnico in Lisbon - Portugal. In 1994 he received the PhD in Electrical Engineering and Computer Science from the Institut National Polytechnique de Lorraine in Nancy – France. He is member of the Center of Intelligent Systems of the IDMEC research laboratory and teaches at Instituto Superior Técnico

in Lisbon courses in Industrial Automation and Informatics areas. He made several post-docs and sabbatical leaves, namely in IRIT and LAAS in Toulouse - France, CERN in Geneva - Switzerland and Schneider-Electric in Seligenstadt - Germany.

His main research interests include industrial automation, real-time systems, fieldbus and wireless communications. He has published over 50 technical papers in these areas.

Address: IDMEC, Instituto Superior Técnico, Avenida Rovisco Pais, 1049-001 Lisboa, Portugal, email: carlos.cardeira@ist.utl.pt

Armando Walter Colombo (Dr., 46) received the Bachelor Degree in Electronics Engineering from the National Technical University Mendoza, Argentina, in 1990; the Master in Control Engineering Degree from the National University San Juan, Argentina, in 1994; and the Doctor-Engineer Degree with a scientific work about intelligent manufacturing automation from the University of Erlangen-Nuremberg (Institute for Manufacturing Automation and Production Systems / Prof. Klaus Feldmann, Germany, in 1998. From 1999 to 2000 he was Adjunct Professor in the Group of Robotic Systems and CIM, Faculty of Technical Sciences, New University of Lisbon, Portugal. In 2001 he joined the Anticipation and Architectures Group, Research & Development Department, Schneider Electric GmbH, Germany. In 2003 he becomes a senior engineer. From July 2004 he serves as Manager of Advanced Projects in the H&O HUB Department, Schneider Electric Product and Technology (P&T), France, Germany and the EU. Dr. Colombo has extensive experience in managing multi-cultural research teams in multi-regional projects and his current role is to integrate worldwide Anticipation / R&D-initiatives of the Schneider-P&T/H&O department. His research interests are in the fields of intelligent supervisory theory, agent- based factory automation, formal specification of flexible automation systems. Dr. Colombo has participated in many international projects and has more than 100 publications per-review in journals, books, and chapters of books and conference proceedings. He is a senior member of the IEEE Industrial Electronics Society, Robotics and Automation Society, the IEEE Systems, Man, and Cybernetics Society and the Gesellschaft für Informatik e.V.. Dr. Colombo is Associated Editor of the IEEE Trans. on Industrial Informatics, Associated Editor of the IFAC Associated Journal ATP-International (Automation Technology in Production), member of the IEEE IES Administrative Committee (AdCom) and chair of the IEEE IES Committee on Industrial Agents (from 2005). He is listed in Who's Who in the World /Engineering 99-00/01 and in Outstanding People of the XX Century (Bibliographic Center Cambridge, UK).

Address: Schneider Electric GmbH, Steinheimer Str. 117, 63500 Seligenstadt, Germany, email: armando.colombo@de.schneider-electric.com

Ronald Schoop (Dr., 48) was born in Schwerin, Germany. He received the diploma and the doctor degree (Dr. Ing.) in Electrical Engineering from the Humboldt-University in Berlin, in 1981 and 1985, respectively. After 3 years in industry, he lead the control group in the department Electronic Technology at the Humboldt-University and received the habilitation (Dr. sc. tech., Dr.-Ing. habil.) in 1990. He joined AEG Modicon in 1991 and after several years in Germany and USA he was the R&D Director for Schneider Electric Automation Business Automation in Germany and afterwards in France. Since 2002 he is the Vice President of the Schneider Electric HUB department in France and Germany.

His research interests are in control and automation, especially in the area of distributed control and collaborative systems. He was project leader of several industrial projects bringing latest research results into industrial use, such as the development of the first industrial agent based control system, deployed in production at DaimlerChrysler (P2000+). He is co-author of 2 books and has published over 50 technical papers in these areas. He has been active in various industrial societies (Technical Director of IDA group, Director of Modbus-IDA, board member of SPS/IPC/Drives conference) and academic societies.

Address: Schneider Electric GmbH, Steinheimer Str. 117, 63500 Seligenstadt, Germany, email: ronald.schoop@de.schneider-electric.com