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Wireless Network Integration into Virtual Automation Networks

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Abstract: Wireless automation is today an emerging topic. Industrial wireless solutions are based on Bluetooth, Wireless LAN, IEEE 802.15.4 or even proprietary radio technologies. This paper describes the functions of different wireless technologies within a Virtual Automation Network (VAN). It is shown how the VAN device architecture is applied to wireless solutions. This includes the definition of generic parameters and exemplification for IEEE 802.15.4 based systems of specific parameters. Finally, the purpose of the formal description is explained in brief.

1. INTRODUCTION

The main idea of the Virtual Automation Network (VAN) project is to have a unique view on a heterogeneous automation network consisting of sub-networks of different wired and wireless technologies. Besides fieldbus systems, industrial Ethernet based system, private, and public wide area networks wireless networks play an important role. Thus, wireless technologies enable mobility and flexibility also for automation applications. The requirement analysis made clear, that these features are of essential importance to reduce costs (e.g. by replacing trailing cables), to improve the reliability of data communication (e.g. by replacing slip rings) and to open up new application fields to automation (VAN deliverable D03.1-1, 2006).

To guarantee that there is virtually only one homogeneous automation network visible, it was necessary to map the different views on different wireless devices to the common VAN device architecture introduced in (Neumann et al., 2007). This is done by specifying Application Service Element (ASE) classes based on the common ASE specification and adding the wireless specific attributes.

In section 2 fields of application are briefly described, since each of the selected wireless technologies (Bluetooth, Ultra-wideband, WLAN and IEEE 802.15.4) addresses a different application field. For each technology typical topologies are introduced which are reasonable for the given application field. According to the open platform and system architecture (Neumann et al., 2007), the VAN device types are indicated within the given topologies. The specification and discussion of the relevant ASEs for these VAN device types is the main subject of this paper.

In section 3 the attributes of a wireless device are explained which are static and describe their characteristic. Thereby, it is distinguished between following attributes:

1. Attributes which are general: these attributes are specified in the common VAN device model and only listed in this paper.

2. Attributes which are general for wireless solutions: these attributes are valid for all wireless technologies. However, in detail there may be additions necessary for one or the other technology.

3. Attributes which are specific for a specific technology: these attributes have to be specified for each wireless technology. This is done in (VAN deliverable D03.2-1, 2007).

Section 4 deals with the general contribution to the VAN ASEs from the general point of view of wireless communication. As in the case of the static attributes, some of the ASE attributes are expected to be defined by the common VAN device model. In these cases, possible additions are proposed.

Section 5 exemplification shows the ASE description for an IEEE 802.15.4 based system. With reference to the global VAN device architecture, the most relevant function building blocks are described in detail.

The definitions are meant to give other working groups of the VAN project the required information to work out VAN related strategies. Thus, the attributes of the Device Configuration ASEs are necessary to specify a unique engineering strategy or to consider wireless networks in the overall VAN plug and play concept (Diedrich et al., 2007). The attributes of the Security ASEs are important to develop a general VAN security approach to overcome isolated security solutions which do not fit to each other (Adamczyk et. al., 2007).

2. WIRELESS TECHNOLOGIES IN VAN ARCHITECTURE

The necessity of several wireless technologies and standards in industrial automation arises as requirements differ from one application field to another. This section provides a brief description of the application fields that are covered best by the chosen wireless technologies.

2.1 Bluetooth

Bluetooth has its advantages in applications when it comes to bandwidth needs in the order of up to 300 kbps and only a limited number of wireless devices per radio cell. Especially, the adaptive frequency hopping together with the transmit power regulation of each individual Bluetooth link makes this technology attractive in applications which need a high density of wireless systems operating independently in the same local area without additional commissioning efforts for a detailed frequency planning and device configuration.

Examples of such applications are small to medium standard machines, where wireless communications is needed to a few rotating or linearly moving parts with a limited number of IOs of the machine. Other examples exploit the possibility of Bluetooth to operate several communication profiles. Bluetooth not only provides a transparent channel for Ethernet communication but also provides services for standard serial communications. This is helpful in cases of diagnostics, maintenance and configuration as described in (VAN deliverable D03.1-1, 2006).

In applications where only simple digital/analog I/O channels are needed, Bluetooth can be used for transmitting only the raw digital/analog IO data instead of a full Ethernet based communication protocol. This makes wireless transmission very efficient and leads to the quickest possible reaction times. Considering VAN in such a scenario, an IO device with the Bluetooth interface acts as a VAN Virtual Device, whereas the Bluetooth base-station acts as a VAN Proxy Device as per (VAN deliverable D02.2-1, 2006), providing full VAN functionality to the connected VAN domain.

2.2 Ultra-Wideband

UWB has many advantages that make it suitable for indoor wireless networks in general and, more specifically, for consumer electronics applications. Basic physics gives UWB an inherent ability to maintain high speed through walls and in cluttered high-multipath environments. UWB is a technology that provides potentially unlicensed operation, simplicity, very low transmit power, multipath and interference immunity, and the capability to deliver data rates in excess of several hundred Mbps all the while consuming very little battery power and relatively small amounts of silicon area, translating to low cost. An UWB radio is designed to transmit less than 75nW of power per MHz of frequency bandwidth, which is equivalent to an aggregated power of 0.26mW, in contrast to 30-100mW for 802.11b WLAN radios and 1mW to 1W for Bluetooth radios. Typical VAN-relevant applications of the UWB technology are listed below (Lakkundi, 2007).

• For drive systems: to replace trailing cables and slip rings even for fast rotating machine parts

• Motion control applications in manufacturing

• Location-aware communications applications

• Tracking mobile objects

• In sensor networks to monitor industrial automation and control

2.3 Wireless LAN

The standardisation body of WLAN is IEEE 802.11, the neighbour of 802.3, where the wired Ethernet has its location. Therefore, WLAN is considered to be the “wireless Ethernet”. With the success of Ethernet in automation, WLAN can be seen as the perfect extension for wire line automation applications. In general, WLAN offers a high data rate (up to 54 Mbps). This makes it applicable where large process files have to be transmitted, but also applications in automation with short data frames but high real time requirements to establish the communication between PLCs and field devices. WLAN helps in fulfilling the demand for reliability as it offers redundancy mechanisms and package retries. In addition, WLAN can be operated in the popular ISM band at 2.4 GHz, but has the possibility to use the 5 GHz-band, which is less crowded. Combined with powerful security mechanisms, this radio technology can be used in applications where failsafe data (e.g. emergency stop) need to be transmitted.

Overview of WLAN applications in automation:

• Wireless HMI (human-machine interface)

• Wireless Control, M2M (machine-to-machine)

• Wireless failsafe

• Mono track rail, AGV (automated guided vehicles), train

• Large plant floors (up to kilometres), temporary installations

• Voice, VoIP (voice-over-IP)

• Cranes, Wind mills

• Mobile service and diagnosis

2.4 IEEE 802.15.4 and ZigBee

Wireless sensor network (WSN) technologies such as IEEE 802.15.4-based devices and ZigBee enable the use of multiple, very low-powered nodes to cover wide areas of interest using low data rates. WSNs are typically used to overcome physical and economical constraints of traditional wired sensor solutions and consequently could find applications in some of the following fields of industrial automation:

• Plant and process monitoring via sensor reading (indoors and outdoors)

• Non-critical closed loop applications (e.g. simple switching applications)

• Wireless network extensions for existing wired field devices

• Location awareness applications (e.g. inventory tracking and asset management)

• Plant building automation and management (e.g. lighting, HVAC, security)

Applications areas where IEEE 802.15.4/ZigBee devices will be prevalent could be for applications requiring battery-operated devices, which could operate in the order of months or years. Most of the deployed wireless sensor network items will be used in simple field devices in high quantities. Due to the small device footprint and reduced onboard resources (e.g. memory and computation power) of the field devices for IEEE 802.15.4 and ZigBee applications, the most likely scenario is that a VAN proxy device (VAN-PD) will be used to integrate IEEE 802.15.4 and ZigBee devices into the VAN Domain. The resulting connected devices to the VAN-PD will therefore be VAN virtual devices (VAN-VD).

3. WIRELESS DEVICE DESCRIPTION ATTRIBUTES

In order to automatically support engineering processes in industrial automation formal descriptions of the device's characteristics are necessary. You can distinguish between static information such as allowed temperature range of the device and dynamic parameters which can be configured or which provide status information during operation. However, depending on the implementation of a wireless device some characteristics may be static or dynamic. One example is the antenna. You may have the option to use different antennas depending on the application's requirements using connectors or the antenna could be build in e.g. as a PCB antenna.

The characteristics can be device related such as the antenna or system related such as the frequency channel. This section lists and explains the possible static information which you will find today in data sheets of wireless devices.

First there are general attributes which are common for all wireless devices of all technologies or even for all VAN devices. These include Device Information, Vendor Information, Maximum Payload, Power Supply Related Attributes, and Available Security Services. The following attributes are common to all wireless technologies.

Radio Technology or Standard

A number of characteristics are already predefined by radio technologies or standards implemented in the wireless devices. Therefore, this parameter can give implicitly information such as modulation and coding for IEEE802.11b, data rate for Bluetooth or band width for ZigBee.

Topologies Supported

Depending on the technology or the implementation different topologies are supported a system. These are: point-to-point, star, tree, and mesh.

Network Device Type

Depending on the technology or the implementation a device can play different rolls within a network. It can be an end device, a router device, an access point or a client. The network device type should not be confused with the VAN Device Type. An end device can be a VAN Automation Device or a VAN Virtual Device.

Quality of Service

The quality of service of a link can be described with following characteristic parameters: transmission delay, response time, update time, and packet loss rate. These characteristic parameters have to be measured under defined test conditions (Rauchhaupt et al., 2006).

Frequency Bands

Different frequency bands can be used for wireless communication. Examples are 2.4 GHz and 5 GHz bands.

Centre Frequencies

This attribute describes which centre frequencies can be used within the frequency band by the device.

Band Width

This attribute describes the frequency area which is used during the transmission. It is fixed for a selected technology.

Channel Separation

This attribute describes the distance between two centre frequencies. It is fixed for a selected technology.

Modulation

This attribute describes the used modulation scheme.

Coding

This attribute describes the used coding for a symbol during the radio transmission.

Frequency Channels

For some technologies frequency channels are defined which can be used instead of Centre Frequency and Band Width to address a certain frequency area within a frequency band. This attribute describes the channels which can be used by a device.

Supported Data Rates

This attributes describes the data rate which is used at the air interface.

Maximum Transmission Power (EIRP)

This attribute depends on the transmit power which can be configured in the device, the power loss of the circuitry and the antenna gain.

Information about the media access control should be provided to be able to estimate the real time capabilities of the wireless network. Depending on the wireless technology or standard there MAC functionality can be configured or not. Following Media Access Related Attributes are relevant:

Media Access Mode

Examples for media access modes are time division media access (TDMA) and carrier sense multiple access collision avoidance (CSMA/CA).

Global Time Period

A global time frame is often defined in order to be able to control the media access. This attribute contains a time value which defines the duration of that time frame.

Number of Retries

This attribute is used to define how often transmissions are retried in case of recognized errors.

4. WIRELESS CONTRIBUTIONS TO VAN ASEs

4.1 Wireless Contribution to General VAN Attributes

This section describes the wireless-specific contribution to the general VAN device model. There are a number of attributes which are common for all wireless technologies. These attributes are described here taking into account that some of them should also be relevant for other components of VAN. For more flexible implementations of wireless devices, overlapping is possible to the already described static parameters. In these cases a reference is made to the related attributes. The description of attributes is based on the object oriented open platform and the system architecture defined in (VAN deliverable D02.2-1, 2006).

Network Type

The four new transmission technologies added to the VAN concept are based on Bluetooth, Ultra-Wideband, Wireless LAN, and IEEE 802.15.4 and ZigBee. Therefore, these new network types are considered by the overall device and system architecture in VAN:

Address Information

The identified wireless VAN device types have to be addressed in accordance to the definition in (VAN deliverable D02.2-1, 2006). Depending on the technology, address translations are necessary.

Supported Internet Protocols

Since wireless devices may implement different kinds of IP services, a related attribute is necessary. This should be in line with definitions for other VAN devices made in (VAN deliverable D02.2-1, 2006).

4.2 Wireless Device Configuration Class

The figure below shows the classes contributed to the Device Configuration ASE as an example for VAN ASEs. There is an abstract class WIRELESS DEVICE CONFIG that defines attributes that are contained in all further derived classes. For each considered wireless technology, a single specific class is defined that specifies the specific structure and attributes needed to use the respective technology within VAN. These single classes are: BLUETOOTH DEVICE CONFIG, UWB DEVICE CONFIG, WLAN DEVICE CONFIG and ZIGBEE DEVICE CONFIG.

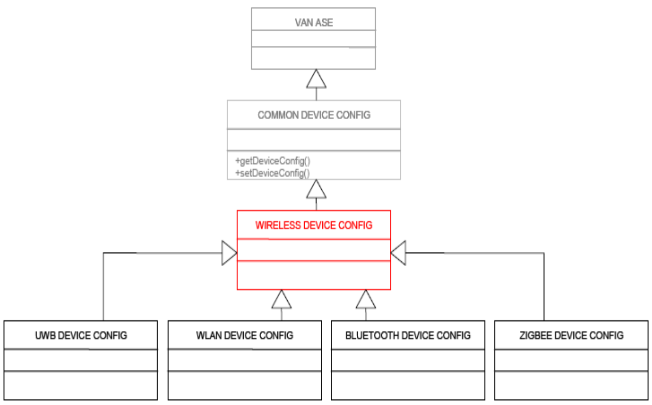

Fig.1. Wireless contribution to Device Configuration ASE

4.3 Formal Model

The Application Service Elements (ASE) are formally described in line with the IEC standards such as (IEC 61158 series, 2006). This is shown below for the DEVICE CONFIG ASE. The description contains references to the related ASE and the parent class. From there attributes and services are inherited. The new attributes are listed in a structure and it is marked as to which of them are optional or mandatory. All the attributes listed here are defined in detail in (VAN deliverable D03.2-1, 2007). Additional services are not required.

VAN ASE: DEVICE CONFIG ASE
CLASS: WIRELESS DEVICE CONFIG
CLASS ID:
PARENT CLASS: COMMON DEVICE CONFIG
ATTRIBUTES:
1 (o) Attribute: PromiscuousMode
2 (m) Attribute: CurrentPowerSource
3 (m) Attribute: PhysicalRadio
3.1 (o) Attribute: CurrentFrequencyBand
3.2 (o) Attribute: CurrentCentreFrequency
3.3 (o) Attribute: CurrentFrequencyChannel
3.4 (m) Attribute: TransmitPower
4 (o) Attribute: MediaAccess
4.1 (o) Attribute: GlobalTimePeriod
4.2 (o) Attribute: IsochronousTimePeriod
4.3 (o) Attribute: AsynchronousTimePeriod
4.4 (o) Attribute: NumberOfRetries

Each of the above attributes belonging to the formal model is quantified based on the respective technology considered.

The security and diagnosis configuration classes are defined similar to the device configuration class depicted above. The respective formal models and the constituent attributes are also defined in a similar way.

5. CONTRIBUTIONS OF A SPECIFIC WIRELESS TECHNOLOGY TO VAN ASEs

5.1 Purpose

This section shows the integration of a specific wireless technology into the class hierarchy of VAN and relevant attributes which are defined in (VAN deliverable D03.2-1, 2007). In this paper we use the wireless standards IEEE 802.15.4 and ZigBee as an example. Based on these standards attributes are assigned to the associated ASEs and described in detail so that they can be used by other to work out overall VAN strategies. IEEE 802.15.4 specifies physical layer and MAC layer for wireless sensor networks. Based on this standard several higher layer implementations are known. One of them is ZigBee another WirelessHART. Here the ZigBee specification is used as an example for higher layer specifications on top of IEEE 802.15.4. Other standards have to specify comparable attributes and a similar device and system behaviour.

With respect to the application field and topologies mentioned in section 2.4 the VAN device types VAN Proxy and VAN Virtual Device are considered. A VAN ZigBee Proxy Device contains one set of ASEs for each VAN Virtual

Device. ZigBee management services are used in order to transfer the attribute date from the VAN Virtual Devices to the VAN ZigBee Proxy Device.

5.2 ZigBee Device Configuration Class

The ZIGBEE DEVICE CONFIG ASE object specifies the attributes that can be used to configure IEEE 802.15.4 or ZigBee devices or networks. It is derived from the WIRELESS DEVICES CONFIG as shown in figure 1.

5.3 Refinement of Inherited Attributes

Sometimes attributes, already defined in parent classes, may have a specific meaning or a certain coding. Some examples are specified below.

Object-reference String

This attribute is inherited from the VAN ASE. The content of the string in this class is "ZigBee".

PromiscuousMode Boolean

This attribute is inherited from class WIRELESS DEVICE CONFIG. The attribute macPromiscuousMode defined in IEEE 802.15.4 is equivalent to PromiscuousMode. It indicates whether the MAC sub-layer is in a receive-all (promiscuous) mode. A value of TRUE indicates that the MAC sub-layer accepts all frames received from the PHY. This could be viewed as a type of packet-sniffing feature.

CurrentFrequencyChannel

This attribute is inherited from PhysicalRadio-structure of the class WIRELESS DEVICE CONFIG. The attribute PhyCurrentChannel (Unsigned8) defined in IEEE 802.15.4 is related to CurrentFrequencyChannel. It indicates the RF channel to use for all transmissions and receptions. The exact channel number allowed is restricted to the range determined by which physical layer is used (see table 1). The channel number used for the network is normally selected by a higher layer based on an algorithm which uses the results returned by the energy detect scan, but this can be manually selected and changed as well. However, the ability to change the channel number is restricted to the PAN coordinator only.

Table 1. Number of channels per band

Frequency	Region	Channels	Input Range
2450MHz	Worldwide	16	12 – 27
915MHz	USA	10	2 – 11
868MHz	Europe	1	1

TransmitPower Unsigned16

This attribute is inherited from class WIRELESS DEVICE CONFIG. In case of IEEE 802.15.4 and ZigBee devices several values to specify the transmit power are possible. This value will be entered directly because of different vendor implementations for setting the RF transmit power. Therefore, the vendor datasheet for the PHY hardware platform used should be consulted to determine the exact input value required to achieve the desired RF output power level. The table below is an example of Chipcon's CC2420 transceivers implementation for the transmit output power parameter. The power amplifier level (PA_level) is the decimal input value required in the specific register (in the CC2420 case this is the 16 bit TXCTRL register) in order to obtain the corresponding output RF power level (in dBm).

Table 2. Transmit power levels

PA_level	TXCTRL register value	Output (dBm)
3	0xA0E3	-25
7	0xA0E7	-15
11	0xA0EB	-10
15	0xA0EF	-7
19	0xA0F3	-5
23	0xA0F7	-3
27	0xA0FB	-1
31	0xA0FF	0

GlobalTimePeriod

This attribute is inherited from MediaAccess-Structure of the class WIRELESS DEVICE CONFIG. The attribute macBeaconOrder (Unsigned8) defined in IEEE 802.15.4 is related to GlobalTimePeriod. The allowable range of this attribute is from 0 to 15. For non-beacon networks, this value will be set to 15. In this case, the network will use un-slotted CSMA/CA to gain access to the medium. For beacon-enabled networks, where the use of a super-frame structure bounded by two periodic signalling beacon frames is used, this value can vary from 0 to 14. The detailed structure of the MAC super-frame is specified by the macBeaconOrder attribute, as well as the macSuperframeOrder.

The Beacon Interval (BI) is the time between two consecutive beacons which includes an active period (the super-frame) and possibly an inactive period (during which time the nodes may sleep). The Beacon Interval (BI) and macBeaconOrder (BO) are related such that the BI = 960 * 2BO where BO can be in the range from and including 0 to 15. A value for BO of 0 will result in a beacon interval of 15.36ms and a BO value of 14 will result in a beacon interval of 251 seconds. A value of 15 for BO will disable the transmission of beacons.

The GlobalTimePeriod is equivalent to the Beacon Interval.

5.4 Formal Model

The following list provides an overview over the additions of IEEE 802.15.4 and ZigBee. Together with the explanation in (VAN deliverable D03.2-1, 2007) all necessary information is provided to configure wireless devices in the same manner as all other VAN devices.

VAN ASE: DEVICE CONFIG ASE
CLASS: ZIGBEE DEVICE CONFIG
CLASS ID:
PARENT CLASS: WIRELESS DEVICE CONFIG
ATTRIBUTES:
1. (m) Attribute: macBeaconPayload
2. (m) Attribute: macSuperframeOrder
3. (m) Attribute: macAssociationPermit
4. (m) Attribute: macBSN

5. (m) Attribute: macDSN
6. (m) Attribute: PhyCCAMode
7. (m) Attribute: macPANId
8. (m) Attribute: macCoordExtendedAddress
9. (m) Attribute: macCoordShortAddress
10. (m) Attribute: macShortAddress
11. (m) Attribute: macAutoRequest
12. (m) Attribute: macTransactionPersistenceTime
13. (m) Attribute: macGTSPermit
14. (m) Attribute: macMaxCSMABackoffs
15. (m) Attribute: macMinBE
16. (m) Attribute: nwkSequenceNumber
17. (m) Attribute: nwkPassiveAckTimeout
18. (m) Attribute: nwkMaxBroadcastRetries
19. (m) Attribute: nwkRouteTable
20. (m) Attribute: nwkMaxChildren
21. (m) Attribute: nwkMaxDepth
22. (m) Attribute: nwkMaxRouters
23. (m) Attribute: nwkUseTreeAddrAlloc
24. (m) Attribute: nwkUseTreeRouting
25. (m) Attribute: nwkNextAddress
26. (m) Attribute: nwkAddressIncrement
27. (m) Attribute: nwkTransactionPersistenceTime
28. (m) Attribute: macAckWaitDuration
29. (m) Attribute: nwkNetworkBroadcastDelivery Time
30. (m) Attribute: macBeaconPayloadLength
31. (m) Attribute: macBattLifeExt
32. (m) Attribute: macBattLifeExtPeriods
33. (m) Attribute: macRxOnWhenIdle
34. (m) Attribute: nwkSymLink
35. (m) Attribute: nwkReportConstantCost
36. (m) Attribute: nwkRouteDiscoveryRetriesPermitted
37. (m) Attribute: UserDescriptor

5.6 Further ASEs

The same procedure is used for other applications services elements. The ZIGBEE SECURITY CONFIG ASE is derived from the WIRELESS DEVICE SECURITY CONFIG ASE. The aim is to provide information to be considered in the overall security concept as well as in the general engineering concept. The defined attributes are those required to manage the security for different levels within the IEEE 802.15.4 (ZigBee) network.

The ZIGBEE DIAGNOSIS ASE is derived from the WIRELESS DIAGNOSIS ASE. The attributes carry information of ZigBee that can be used for monitoring and diagnostic purposes. These are parameters whose values can change during runtime and access to it could provide useful data for diagnosis.

6. CONCLUSIONS

Wireless technologies are expected to be prominent in future heterogeneous automation networks. They ensure the implementation of mobile, movable or flexible industrial automation applications. Therefore, these technologies are integral to the overall approach of VAN.

None of the technologies discussed above has been developed for automation applications; however the IEEE 802.15.4/ZigBee specification has industrial measurement and control as well in its scope. Nevertheless, Bluetooth and Wireless LAN industrial products are already on the market. This paper provides the necessary descriptions that are required to integrate products based on these technologies into the general configuration, plug and play, security and maintenance approaches of VAN. ZigBee is the only available higher layer specification for networks based on IEEE 802.15.4 today and has thus been chosen to show how sensor network related attributes can be taken into account within the VAN concept. Furthermore, this paper makes an effort in integrating UWB into the VAN architecture in the form of contributions of the pertinent ultra wideband specifications into various VAN ASEs. These ASEs are mainly, device configuration, security configuration, diagnosis features, and relevant MAC parameters for the adaptation layer, which are specified with the aim of facilitating subsequent implementation of UWB design and test specifications in the chosen industrial environments.

Finally, the specifications described in this paper illustrate that solutions of the chosen wireless technologies can be part of VAN. This means these technologies can be planned, configured, commissioned, diagnosed, and maintained by VAN methods in the same way as industrial Ethernet solutions or public networks which are also part of VAN.

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