Embedded multi-core systems for mixed criticality applications in dynamic and changeable real-time environments

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Publishable Executive Summary

Internet of Things (IoT) defines a scenario where everyday physical objects will be connected to the Internet, will interoperate with other objects and systems; and will be able to identify themselves to other devices. This will increase dramatically the number of connect items to the networks that could be transformative of daily life.

The number of IoT device connections worldwide increased from 173 million in 2013 to 2.2 billion by 2023, growing at a compound annual growth rate (CAGR) of 29%[1]. IoT&M2M communication market in 2013 was worth $10 billion, and is expected to grow $88 billion by 2023. It is expected to have an increasing CAGR of 24% from 2013 to 2023[2]. The challenges rely on the higher computing resources needed to process the increased amount of data available, as well as safety and security issues in open and dynamic environments.

WP11 focuses on different scenarios that will be addressed in a short future and where the focus of this project will help to develop new functionalities. WP11 includes five use cases that will allow showing implementations like audio and video communications over WebRTC (using the web browser as the device), open deterministic networks, automatic home networking, ultralow power high database communication, and synchronized low-latency deterministic networks. This document presents these five use cases within the IoT domain:

- The first use case will address large-scale application of Unified Communication Services using HTML5 based Web Browsers on Embedded Systems. The main goal is to have the possibility to adapt these systems to the new paradigm where the web browser is going to be the player. An additional target is to showcase the capability ofthe WebRTC technology and paradigm to be integrated with digital and analog radio communication systems in safety critical communication applications in the domains public transport, public safety and air traffic management.
- By open deterministic networks the second use case will try to demonstrate that the developments conducted have been taken to the next level in cross domain industrial applications. The aim is to showcase the potential of open deterministic networking by connecting a variety of local embedded systems to other embedded systems in the area of transportation industrial domains. Such an open deterministic network together with mixed-safety-criticality applications and security-domain-separated applications utilizing multicore technology potentially enable public transport and public safety organizations to utilize the same network infrastructure and network devices where today multiple infrastructures are used.
- The third use case will use the results of other WPs to test a data aggregator to be applied in home environment to process sensors' and identification data of things.
- The use case "ultralow power high database communication" wants to realize a multiprocessor platform which achieves a power consumption that is a factor lower than present state of the art. This will be done by the realization of a 802.11n/ah medium data rate, ultralowpower solution, where the lower power can mean a breakthrough in terms of overall system power and cost.
- The fifth use case will demonstrate the benefits of applications using low latency networks with high accuracy time synchronization. The objective is to provide synchronization capabilities of distributed multicore systems with an accuracy of few hundred of picoseconds. This will help in areas like high accuracy positioning systems.

[1] Analisys Mason, 2013
[2] Analisys Mason, 2013

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1. Introduction

1.1 Objective and scope of the document

This document provides an overview and requirements of the five use cases in WP11. The objective is to show a detailed description of the demonstrators and their system requirements, and to provide a list of measures to be done at the end of the project to evaluate the objectives of the use cases.

1.2 Structure of the deliverable report

This document is organized as follows: the sections 2, 3, 4, 5 and 6 present the five use cases in WP11. Each of the sections provides an introduction of the particular use case, a description of the demonstrators to be deployed, a detailed description of the requirements for the demonstrators, as well as a list of measures and indicators to validate the demonstrators at the end of the project. Section 7 lists the references.

2. Multimedia communication WebRTC

2.1 Use case introduction

This use case will address large-scale application of Unified Communication Services using HTML5 based Web Browsers on Embedded Systems. HTML5 offers new capabilities to create web pages, especially in terms of dynamic elements. WebRTC is set of technologies that are being standardized by the IET, W3C and 3GPP. WebRTC allows the possibility to have multimedia sessions (audio, video, chat, etc) from any browser and device with no need to install or update anything, so this technology is called to be the next big thing in unified communications during the next years.

WebRTC defines an API in the browser so that it can be used as a real-time multimedia terminal (audio, video, file transfer, screen sharing, etc.). Websocket new transport protocol, defined by HTML5, is a perfect complement to WebRTC technology as it allows to easily exchange signalling information between the browser and the server.

WebRTC technology was initially designed having browser-to-browser real-time communication in mind, but it allows to be used in conjunction with different kinds of servers to provide additional and interesting services such as videoconferencing and connection to PSTN.

The independence from the platform or the type of device, together with the fact that there is no need to install or update anything, is going to make easier the adoption by end users. This represents a big opportunity for telecoms and enterprises to offer or expose new services.

The main goal of this use case is to implement HTML5 and WebRTC in small embedded systems. As these services are available in any device with a browser with WebRTC support, different options are available to evaluate results of EMC². Devices like Raspberry Pi, Firefox OS smartphones, devices based on Intel smart devices for WebRTC, HDMI dongles, Chromecast are some examples of embedded devices ready to work with WebRTC.

Attending to the motivation on the use case and taking into account the possibility to evaluate the results and indicators we have chosen a device of the family of Android TVs that have a reduced size, runs an Android OS with browsers with WebRTC support and have the possibility to add multimedia peripherals (camera and microphone).

The application will be a peer-to-peer videoconferencing solution between two devices that can help to evaluate the quality of experience (and multi-core processing performance). In addition, a method to exchange data via datachannels will be available, as a tool to promote this solution for machine-to-machine communications.

Radio communication is very important in safety critical environments like air traffic management and public safety. Radio communication systems differ in terms of communication and interaction paradigms from communication systems that are based on or have evolved from telephony systems. The well known “Push-To-Talk” feature is a representative example with a technological impact on radio communication systems.

In addition to the before mentioned goals this use case aims for the integration of WebRTC and radio communication standards and technologies, by designing and implementing a WebRTC based radio communication application and an appropriate embedded system.

2.2 Description of demonstrators

WebRTC, as a technology that is focusing on multimedia communications with support for different devices, can be the basis of hundreds of different implementations and use cases. This demonstration will focus on how WebRTC can be used in a multi-core embedded device designed to act as a webTV device (androidTV in this case).

These devices have been designed to bring new capacities to the TV, especially for those that are not “smartTV” thanks to having a CPU running an Android OS with the possibility to run YouTube videos, games, TV on demand, Skype, etc. One of the features available is web browsers like Google Chrome that is fully supporting WebRTC today.

Figure 1: App screen

Chrome with WebRTC is working in devices with Android OS with a different flavour than Chrome for PC. This means that not all the methods defined in the W3C are supported, but in order to solve this issue, Quobis provides an abstraction layer that make the applications work in both scenarios. Using WebRTC means that we don’t need to develop or program an ad-hoc application for each platform. It also means that it is independent of an AppStore and probably the most important point is that, thanks to Quobis abstraction layer, customers do not need to install or uninstall it.

In this use case we will evaluate a web collaboration tool with audio, video and chat support. The usage of video is critical to help to evaluate the performance of the multi-core processor as it is the multimedia feature that requires more computational efforts. This application will allow having a video session from a TV (using the embedded device) or any other user equipment with a WebRTC enabled browser. In addition we can explore the usage of different multimedia tools (i.e instant messaging) to evaluate the user experience. In order to evaluate better the quality of user experience we will use two embedded devices and a commercial laptop, to have three devices ready to make different tests, but any other user devices might be used here.

First we will try to make this multimedia sessions work on this environment, second we will deal with the authentication challenge. An important innovation of the overall approach to be analysed and specified in this UC is the development of an identity framework (IDM) that will enable dynamic device identification and service resolution over the IP network, while at the same time preserving data privacy. This solution will open the way for the support of a large variety of administrative (authentication, accounting), network (identification of the end-device, network connection), or service (personalization, policies) issues crucial for achieving maximum quality of experience.

This is the reason why we will use a WebRTC Application Controller as the element that hosts the WebRTC application that we will test. This element has been designed taking into account the statements released by the 3GPP standardization body that defines a WebRTC portal based on two components: the WebRTC Server Function and the WebRTC Application Function. The objective of this architecture is to serve WebRTC applications fully interoperable with the core network of communication service providers, to manage not only the provisioning of the app to the user devices, as this elements is exposing some APIs or connectors to HSS, OSS, BSS, etc to deal with authentication (different ways to manage identity may be implemented) authorization and user policies/privileges or accounting.

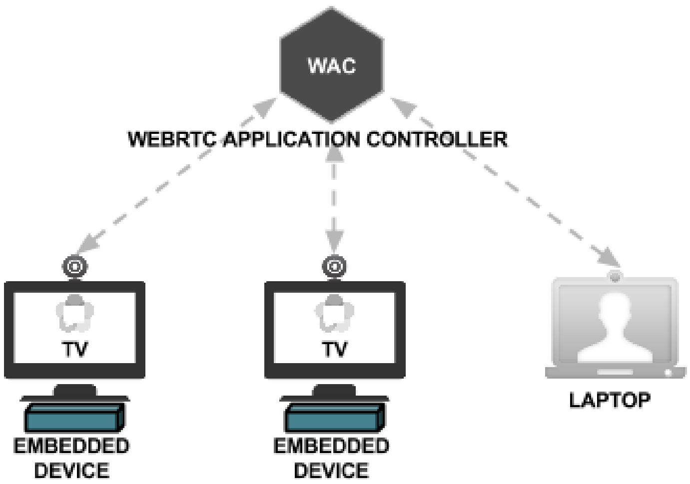

Figure 2: Architecture to be designed and implemented

The radio communication application will finally be demonstrated with a dedicated embedded WebRTC radio touch terminal built by Frequentis (FRQ). The key feature of this demonstrator is the seamless integration of radio communication paradigms, such as Push-To-Talk, into an (partly embedded) WebRTC system architecture.

The respective parts of the demonstrator are an embedded WebRTC radio client (smartphone as well as a radio touch terminal), a WebRTC server and a WebRTC-to-radio gateway. Throughout the project the demonstrator we will evolve in three steps. Step 1 will be a smartphone based WebRTC client in a typical WebRTC system architecture and a radio web application. Step 2 will integrate a WebRTC-to-radio-gateway. The final demonstrator will then support and integrate an embedded WebRTC radio terminal.

2.3 Requirements of the system

To develop the use case mentioned before we need two embedded devices with Android+WebRTC support and a HDMI connection, two external cameras with microphone, two monitors or TV with this interface available and a PC/laptop with a WebRTC-enabled browser. To run the WebRTC Application

Controller we will use a general purpose virtual machine based on VMware that will host an OVA with this element ready.

As embedded device we have chosen the MINIX NEO X7 Mini, a device that was released in September 2013. It is the scaled-down version of the NEO X7 but with similar capacities in terms of CPU and RAM. This element is part of the family of Android TVs (linked with elements like HDMI dongles, AppleTV or ChromeCasts).

It runs an Android 4.2.2 with different web browsers that can run WebRTC applications. This element has an HDMI interface (thought to be plugged into a TV) with 1080p HD video. Supports mouse and keyboard, and it's easy to add a camera a microphone to have a complete WebRTC session. In addition, it has been designed to support Android games, so video processing capacities is enough to deal with video contents over WebRTC.

The main features of this device are:

Table 1: MINIX MEO X7 Mini features

Processor	Quad-Core Cortex A9 Processor
GPU	Quad-Core Mali 400
Memory	2GB DDR3
Internal Storage	8GB NAND Flash
Wireless Connectivity	802.11n Wi-Fi, Bluetooth 4.0
OS	Android™ Jelly Bean 4.2.2

The WebRTC Application Controller will run on a virtual machine based on VMware with following minimum requirements:

- Architecture Intel x86 processors, 64 bits
- Number of CPU cores 1x CPU core
- Processor speed 2.0 GHz or higher
- RAM At least 1 GB memory
- Disk space 18 GB hard drive or higher
- Network Interfaces Single Ethernet 1000base-TX NICs
- IP Addressing One (1) IP address

The rest of the elements like PC/laptop and TV/monitor will be generic, as they are not critical to evaluate the results of this use case. The cameras for the embedded devices will be HD 1280*720 from Logitech (model c920) with embedded microphone. It is important to mention that WebRTC is supporting this media quality:

For audio it uses Opus codec. This is a royalty free codec defined by IETF RFC 6176. It supports constant and variable bitrate encoding from 6 kbit/s to 510 kbit/s, frame sizes from 2.5 ms to 60 ms, and various sampling rates from 8 kHz (with 4 kHz bandwidth) to 48 kHz (with 20 kHz bandwidth, where the entire hearing range of the human auditory system can be reproduced).

For video it uses VP8 or H264. We will work with VP8 here. VP8 codec minimum bandwidth is 100kbits/s VP8 codec maximum bandwidth is 2000+ kbits/s based on different rates and frame sizes, including: {1280, 720} the maximum resolution of the camera, {960, 720}, {640, 360}, {640, 480}, {320, 240} and {320, 180}.

The key requirements for the radio application demonstrator are:

- The demonstrator shall establish a bidirectional audio connection from an embedded WebRTC radio client to a radio interface. The audio codec used shall be G.711.
- Radio communication paradigms, such as Push-To-Talk shall be seamlessly integrated into WebRTC system architecture and user interfaces.
- The demonstrator shall integrate an embedded WebRTC radio touch terminal supporting Frequentis communication system platform software.

2.4 Measures and indicators

In order to evaluate the performance of the multi-core processor we will consider subjective and objective KPIs based on media quality like:

- Packet loss
- Video frame rate used
- Video frame size used
- Video frame loss
- Security and authentication
- Subjective perceived quality
- Subjective user experience

A Frequentis radio tester/simulator (connected to the WebRTC-to-radio-gateway) shall be used to verify the radio application requirements:

- Bidirectional audio connection.
- Presence of radio signalling information like Push-To-Talk, etc.

Audio and Push-To-Talk delay are the most important performance indicators in radio communication and shall be measured for the WebRTC radio communication demonstrator.

The verification of the Frequentis communication system platform software on the new WebRTC radio touch terminal will be implicitly tested.

3. Open deterministic networks

3.1 Use case introduction

This use case targets to demonstrate that the developments conducted within the WPs of this project with respect to open deterministic networks have been taken to the next level in cross domain industrial applications. The aim is to showcase the potential of open deterministic networking by connecting a variety of local embedded systems to other embedded systems.

While the IoT today is characterized and dominated by uncritical (i.e. non-safety related) applications that follow best-effort communication scheme, the increasing integration of also safety-critical domains such as transportation or (industrial) automation is the today a megatrend. Hard real-time networking and control are traditionally fields in which safety, security and guaranteed operation are key requirements. Such systems have typically remained closed or semi-open to the wider Internet network. The real-time IoT is the trend that will drive the application of IoT connectivity to hard real-time systems. For example: Wind turbines that are precisely controlled in hard real-time over the same infrastructure as data is being transmitted and analysed remotely, autonomous cars that are controlled in-vehicle but can also interact with their physical environment, and robots that are able to safely move around factory floors and work together with the human workforce.

Last but not least, the real-time IoT as envisioned in this demonstrator is an enabling technology for future System-of-systems (SoS), where distributed components or systems will be connected and integrated towards larger systems only when adequate networking infrastructure becomes available that is in particular suited for mixed-criticality integration,.

3.2 Description of demonstrators

3.2.1 Open deterministic mixed-criticality networking

In this demonstrator, TTTech with some of its cooperation partners such as DTU will develop a mixed-criticality networking platform that is able to address the challenges and demands of future networked system, mainly the IoT. The goal is to develop and demonstrate a networking platform consisting of end system devices (IoT nodes) and additional required networking infrastructure (e.g. switches and backbone networks) that is capable of:

- Guarantee of Service on the network, providing inherent guarantees for safe and secure communication to the applications
- Interconnection of heterogeneous embedded systems (partly) over public network infrastructure such as the Internet
- Converging multiple traditionally separated networks that can be of high complexity, into a single network without compromising the required safety, security and timing levels.

The basis for the demonstrator will be TTTech's TTEthernet technology (cf. Figure 3) which will be extended and/or adapted to meet the additional requirements of real-time IoT systems. Main focus will be given to the mixed-criticality considerations on the network which can later be expanded to provide true end-to-end guarantees for composed mixed-criticality applications on a chip-, device-, network- and integrated system level.

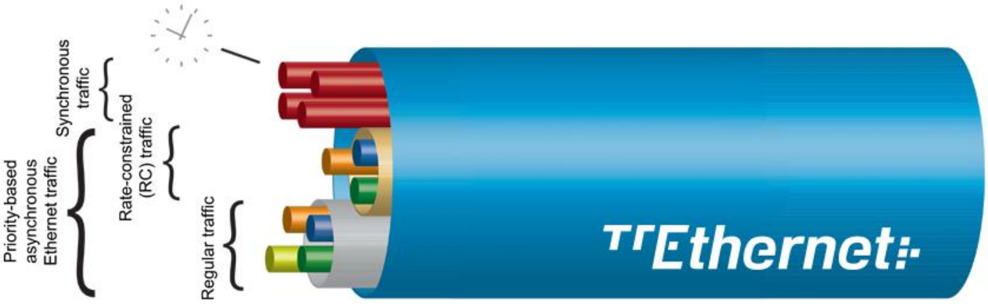

Figure 3: Mixed-criticality networks for the real-time IoTbased on TTEthernet

DTU has developed a design optimization tool named DOTTS for TTEthernet systems that determines the routing of frames in the network, the schedule of the TT frames and the packing of messages in frames such that all frames are schedulable and the worst-case end-to-end delay of the RC messages is minimized. In this demonstrator, DTU will integrate DOTTS in the TTTech tool chain, and we will show that by using DOTTS we can increase the performance and the traffic utilization of the TTEthernet networks.

Furthermore, DTU is currently developing an optimization tool for incremental scheduling of TTEthernet networks, which allows adding new TT traffic with no or minimal impact on existing traffic, thus minimizing the revalidation and recertification costs of the system. DTU will also integrate this new scheduling tool in the TTTech tool chain, and we will show that by using this new tool, system integrators can add new traffic to an existing system, with minimal recertification costs and potentially allowing system integrators to update the TTEthernet schedules online. Finally, DTU is currently developing a novel RC worst-case end-to-end analysis that provides very tight worst-case end-to-end delays. Such an analysis will further increase traffic utilization of TTEthernet networks. In this demonstrator we will also compare the results obtained by the novel analysis together with the real end-to-end delays as recorded from the system.

3.2.2 Mixed-criticality tactical voice communication systems

Based on an existing Frequentis multiprotocol gateway solution a tactical voice communication system with criticality separated applications utilizing multicore processors will be developed and integrated in the above described network infrastructure in this demonstrator.

In the current solution, applications with mixed criticality (safety critical gateway applications, non-safety critical management or other network services) run on the same single core system. With this demonstrator criticality separation in several consecutive steps will be developed. The stepwise approach has the advantage that the different steps will provide a scalable solution for different levels of separation requirements in different field applications:

- In the first step, the gateway is upgraded with multicore hardware. Then, the existing Frequentis Linux distribution has to be ported to the multicore hardware. Safety critical and non-safety critical applications within one operating system instance shall be bound to separate cores.
- In the second step two operating system instances (Linux) shall run bare metal on two different cores. Therefore, it is necessary to separate the resources of the system and uniquely assign them either to the first or the second core.
- The third step is to create a design concept and to identify advantages and disadvantages of utilizing a bare metal hypervisor from a separation perspective. The solution from step two shall

be eventually be modified so it could be running on a separation hypervisor. However, it is out of the scope of to actually implement the hypervisor solution.

In a typical application several such gateways are used in a larger network. The demonstrator will consist of two gateways, which are connected via Ethernet to the above mentioned network infrastructure in all different steps. The traffic from and to the different applications will be separated according to the criticality level at the network and system level.

3.3 Requirements of the system

The main requirements of the envisioned use cases may be categorized as follows.

- Development of an interconnection possibility for systems of mixed-criticality over open networks
- Integration possibility for existing, heterogeneous devices and systems into the mixed-criticality network infrastructure
- Co-existence of messages belonging to different traffic classes on one physical network (time- and space partitioning)
- Compliance to established standards of the Internet world, in particular of the IEEE 802.1 family
- Definition of mechanism that allow the dynamic integration of new devices or new messages on the network.

For the tactical voice communication system demonstrator the key requirements are:

- Mixed criticality applications shall be separated on different cores and/or on different operating systems on the same platform.
- The Frequentis Linux distribution shall be ported to a multicore architecture.
- A concept for the utilization of a hypervisor shall be developed.

3.4 Measures and indicators

In order to evaluate the performance of the mixed-criticality networking infrastructure we will consider subjective and objective KPIs based on frame transmission quality such as:

- Jitter of messages
- Delay of messages
- Packet loss
- Correct priorization of traffic classes
- Co-existence of different traffic classes over one integrated physical network

These will be tested both in isolated modes (not mixed-criticality) and in various combinations between safety-critical, priority-based and best-effort traffic.

4. Autonomic home networking

4.1 Use case introduction

Home networks currently are based on versatile coexisting technologies, including, among others, IEEE 802.11n, Fiber-to-the-home (FTTH), shorter range wireless technologies such as ultra wideband (UWB) and 60GHz systems, optical wireless technologies working at the infrared and visible portion of the spectrum and wireline alternatives may also be considered relying on VDSL2 or powerline communications (PLC), Ethernet or even multimode and plastic fibers.

Nevertheless, there are numerous challenges regarding autonomic home networking applications. First, the home network is neither monitored nor configured by a network administrator while the end user usually has little or no technical skills.

In addition to that, a complete home network should be able to implement self-x functionalities, namely (i) self-configuration, i.e. a new device should be easy to connect without any intervention from the user, (ii) self-healing, i.e. link disruption and/or device failures must be handled by the terminals and the network themselves in a user transparent manners) and (iii) self-optimization, i.e. the network must configure itself in order to optimize its resources and prevent resource shortage.

Having in mind the aforementioned requirements for an autonomic home network, the main objective of this use case is to **design, develop and implement all technologies that are relevant to management of home networks in accordance with the autonomic computing paradigm.**

The use case will have potential application innovations in regulated domains, including (i) smart homes innovations with emphasis on management systems, (ii) autonomic algorithms and autonomic computing, (iii) smart home metering and smart home energy management and (iv) implementing self-x features towards autonomic systems within home networks.

The partners related to this use case are HUA, IMA and AMBAR.

4.2 Description of demonstrators

The envisioned demonstrator will be based on an autonomous smart home system. Data will be gathered from a set of sensors embedded inside the house, regarding both the environment and the state of the user. The data will be aggregated and analysed, and the system will decide upon how devices in the house should operate in order to meet the user's needs. Moreover, data from energy meters will be gathered in order to ensure that the whole smart home system is energy – aware and leads to energy savings with respect to the case of a typical home.

In that framework, the three partners will collaborate and join their complementary expertise towards the demonstrator implementation as follows.

4.2.1 The demonstrator's main infrastructure

A basic system will be used, provided by IMA, as a basis for the autonomous smart home demonstrator. The wireless part of the system to be used is formed by Jennic (NXP) microcontrollers. A proprietary network layer over the IEEE802.15.4 standard has been developed as an efficient replacement for the ZigBee (and JenNet). Each device in the network can perform any subset of these tasks:

a) to be a data source: These devices usually get data directly from attached or embedded environment sensors. Data from data sources are sent over the network to the nearest.
b) to be a data collector device: A data collector device is a network node which collects data incoming from the wireless network and passes them to a gateway, to which it is attached (usually by USB). To satisfy scalability and reliability needs there can be multiple data collectors in a single network
c) to be a router node: A router node routes data from data sources to data collectors. When there is no need to save a power on a data source device, then this device usually serves also as a router node.

The current gateway system is a tiny power efficient single core x486 compatible device. It runs a full featured Linux OS (Debian Wheezy). There are some daemon processes on the gateway, which collect data from USB (USB to serial converter) and store them temporary in a small internal database. An http server hosts some (mostly RESTfull) services to provide interface to the data. Data can be also retrieved directly by a simple network socket. The current main goal in the gateway development regarding the use case's demonstrator is to create a standardized SoA platform to allow easy development and deployment of 3rd party services.

In the aforementioned system, Freescale ARM based wireless transceivers and microcontrollers in the 802.15.4 2.4GHz band will be used and integrated. Possible sensors to be embedded into the PCB or design as add-ons to the existing platform include RFID / NFC, Fingerprint readers, Gyroscopes / Accelerometers / Magnetometers, etc. Other sensors (Vibration / Humidity / Temperature, etc.) will be considered as well.

For the demonstrator, an embedded module based on the Freescale Vybrid platforms with a Cortex A5 + M4 will also be developed, that allows the building of mixed critical solutions. For instance, the Cortex A5 allows include a Linux platform to port the current existing platform, while the M4 allows to include a bare bone implementation or the MQX RTOS to support critical real-time processes. Finally, communication interfaces will also be added: Ethernet with a fully TCP/IP stack, 802.15.4 transceiver and antenna etc.

4.2.2 Demonstrator's additional characteristics

After the development of the smart home system's infrastructure, the demonstrator will be enhanced by the implementation of advanced data aggregation and data analysis algorithms, towards the minimization of time delays and the maximization of the level at which the consumer's needs are satisfied. Thus, advanced control techniques will be investigated and implemented.

In addition to that, the overall demonstrator aims at being energy – efficient and in that framework, energy meters will be adopted to the overall system and exploited in order to ensure minimization of energy consumption in the envisioned smart home.

Figure 4 depicts the main components of the demonstrator, while Figure 5 presents its main characteristics.

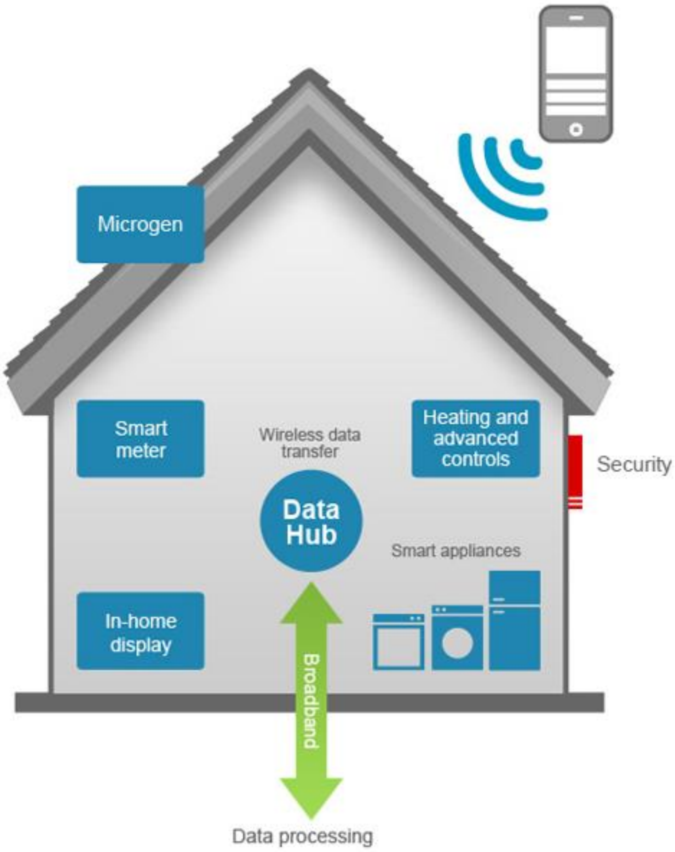

Figure 4: Autonomous smart home demonstrator

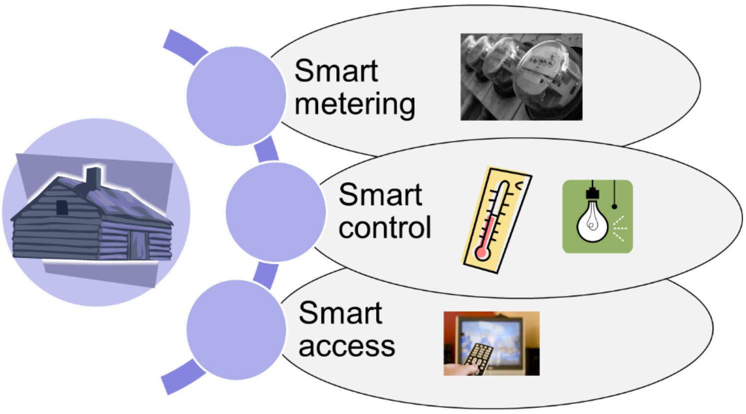

Figure 5: Main characteristics of the smart home demonstrator

4.3 Requirements of the system

The main requirements of the envisioned system may be categorized as follows.

The system should be:

- Pervasive, in the terms of becoming as much unnoticed by the user as possible, while fulfilling all his needs
- Autonomous, in the terms of being able to
  (i) Operate with as less human interaction as possible,
  (ii) Incorporate context - awareness with respect to the knowledge of the environment
  (iii) Incorporate context – awareness with respect to the knowledge of the user's state
  (iv) Apply self – healing and self – optimization procedures
- Secure
- Energy – aware, ensuring that the system leads to less energy consumption when compared to a typical home's operation
- Efficient, in terms of data gathering within wireless network
- Service oriented, developing WPAN/LAN Gateway which will provide SoA platform.

4.4 Measures and indicators

The main measures and indicators to be used in the envisioned demonstrators are the following:

- Energy measurements, to verify reduced energy consumption within the house
- Time measurements, in order to verify that the system introduces minimum delays
- Measurements regarding the level of user needs' satisfaction, based on feedback provided to the autonomous pervasive system
- The network will reliably deliver data from sensors within a reasonable time even in a network with dense traffic. A dynamic environment with sensors generating variable data traffic will be created for testing purposes.
- Service management on the gateway will be demonstrated as well as concrete services for handling sensors and data generated by a wireless network.
- Openness, to provide open API based on open standards to ensure future integration with third-party systems

5. Ultra low power high data rate communication

5.1 Use case introduction

Wireless communication is omnipresent in our actual world. Radio interconnect on the body, connecting pedometers, heartbeat meters, etc to a central intelligent hub monitoring the health condition of the individual is one example. Interconnecting various sensors and devices in the home through a sensor network is another example. With the advent of 'the internet of things' this evolution is only starting and a new wave of radio communication devices is coming.

This growth requires a large autonomy of the appliances. Important research on energy scavenging proves that power consumption has to be further reduced before scavenging technology can be brought to the market. Batteries will remain needed in the future. Even when the appliance is not mobile, they are battery fed and the required lifetimes on a single battery is 10 years or longer.

This demonstrator proposes a novel, ultralow power, twin processor architecture realizing the complete [digital] physical layer and baseband part of a high datarate communication standard. The twin processor platform will realize a combo 802.15.4 and Bluetooth Low Energy standard. The goal is it, to be scalable to other standards like medium datarate WLAN. [802.11n]

The core of the demonstrator will consist of a silicon implementation. As silicon technology a 55nm TSMC technology has been chosen. The chip will also contain the RF [radiofrequency] part. This is however not developed inside this EMC2 program. The software stack running on top of the two processors is a key part of the overall solution.

The goal of the demonstrator is to show breakthrough performance in terms of several power consumption metrics, which will allow to use very small batteries and/or ensure very long battery lifetime. The other goal of this demonstrator is to realize these ultralow power targets and at the same time achieve excellent communication performances, e.g. link-budget.

The solution will also contain software stacks, realizing 802.15.4 and Bluetooth Low Energy. It will be analyzed which are the different network protocols important to these standards: Thread[3], 6LowPan[4], Zigbee, Zigbee-Pro, RF4C, etc. Software architecture and an appropriate wireless sensor operating system will be analyzed. Operating system alternatives are RIOT[5], Contiki[6], TinyOS[7], Linux, etc The RIOT operating system is a promising recent open source European initiative focused on embedded nodes networks that requires low power and computational resources.

The target is to define and port to the platform an overall solution/stack which is based heavily on open standards and which is also based heavily on software available as open source.

5.2 Description of demonstrators

BlueICe will work on a twin-processor demonstrator that is a low-power device with a radio interface.

The device has a radio front-end that is Bluetooth v 4.2 Low Energy capable, and is also capable of ZigBee 802.15.4 operation. Both radios operate in the 2.4 GHz ISM band.

3 http://www.threadgroup.org/
4 http://6lowpan.net/
5 http://riot-os.org/
6 http://www.contiki-os.org/
7 http://www.tinyos.net/

The whole chip is intended to be designed for the very low power, which means:

- The chip has a deep sleep state, where the power to most of the logic is switched off, and where the fast 24 MHz crystal is stopped.
- The processor clock is kept as low as possible to conserve power. The current design goal is to be able to maintain the radio link with a processor clock of not more than 4 MHz.
- There are 2 processors in the device, one to maintain the radio link, and run the radio application stack, the other to run the user code.
- One of the processors will run the link-layer stacks, and can also (help to) run the PHY (not included in the scope of this demonstrator). The other processor is intended to run application stacks. A key design goal is to develop/research an efficient, high performance and low power inter-processor communication mechanism.
- Another design requirement is to have a software development environment which allows fast/efficient verification of the interworking of the 2 processors software and the hardware.

The statements above give a summary of the main goal of this demonstrator. The design work which will be done under this project is all aimed at achieving these goals, or to make these goals possible.

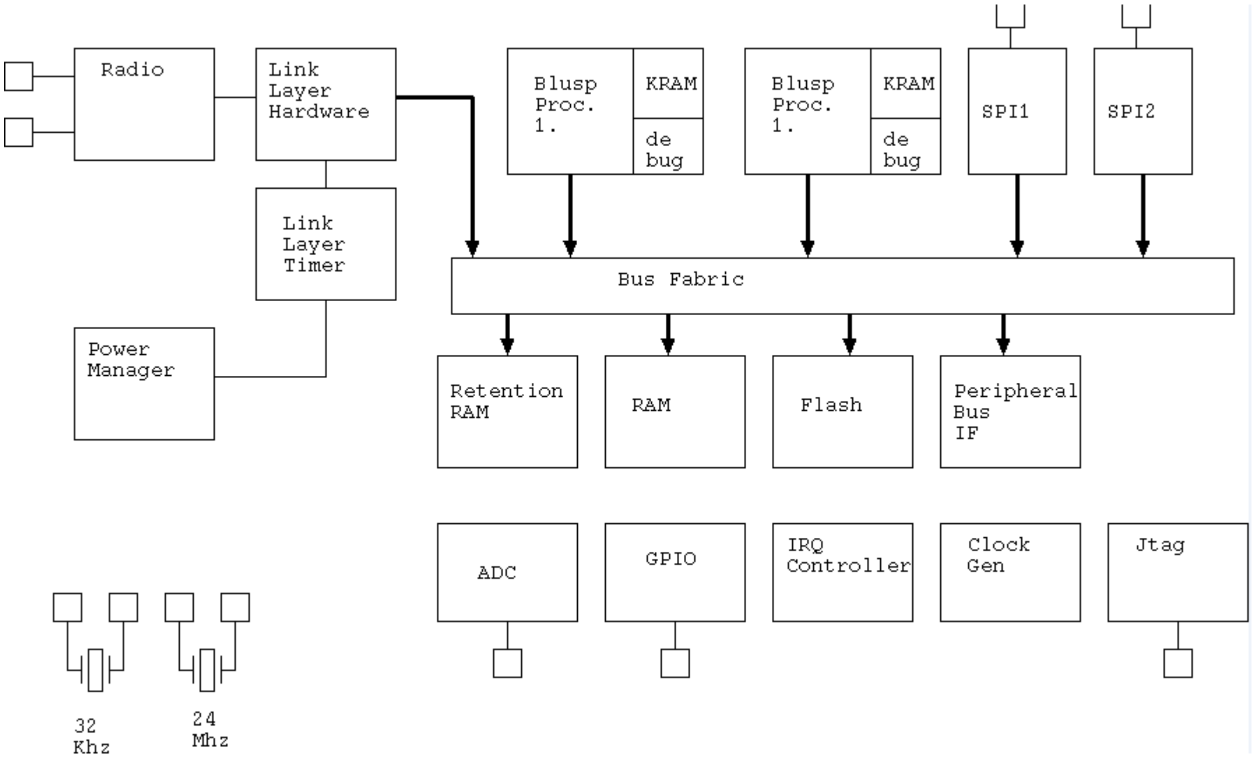

Figure 6: Demonstrator block diagram

Furthermore this architecture is targeted to be scalable to higher data rates up to data-rates of several Mbit/s as can be found in standards e.g. 802.11ah, low data-rate 802.11n.

5.3 Requirements of the system

- High performance and low power capability of the processor block. The solution will be based on the BlueICe BLUSP processor, which with its 3 instructions per clock capability is excellent at realizing high throughput at low clock rates.

- High performance, efficient to use twin-core debug environment.
- SPI-based debugger that can survive the deep sleep mode. Problem with JTAG debugger is that they require the JTAG interface to be powered in order to be able to run the debugger. This is an issue in this device, as the goal is to put the device in a sleep state most of the time where the JTAG is not powered. The issue can be resolved by doing a SPI debugger.
- Low power / high performance inter processing communication protocol to let both processors communicate.
- High performance compiler in order to boost efficiency.

5.4 Measures and indicators

- System power dissipation. This metric needs to be compared to state of the art system solutions for the same radio-links.
- Efficiency of the compiler/processor in code density and instructions per clock cycle vs ARM m0 and ARM m3 together with ARM gcc compiler.
- User friendliness of the development environment.
- Processor clock speed, processor power required to execute a certain function compared with competition devices.
- (Soft) Scalability of the overall environment towards other high data-rate standards.

6. Synchronized low-latency deterministic networks

6.1 Use case introduction

The Smart Grid combines electricity and IT infrastructure to integrate and inter-connect all users (producers, operators, marketers, consumers etc) in order to continue to efficiently balance demand and supply over an increasingly complex network.

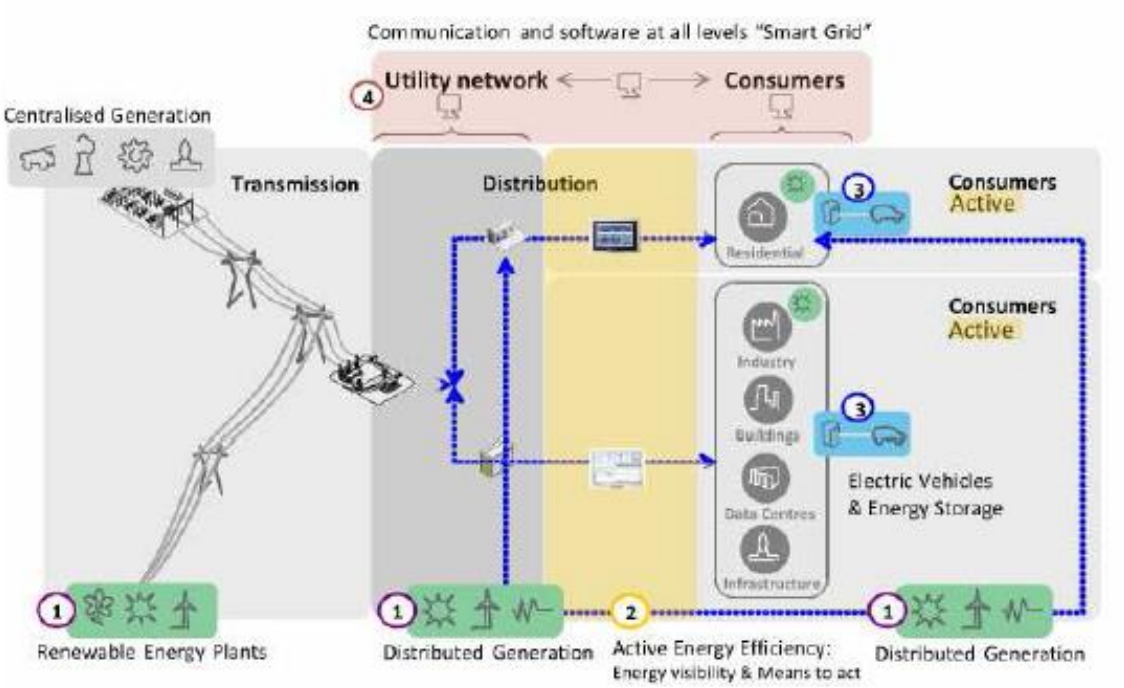

Figure 7: Smart Grid concept

The evolution of Smart Grid imposes the utilization of dependable communication network. Key parameters are availability, safety, security and reliability. At the same time the utilization of widespread infrastructures like Ethernet networks is desirable. For this end, single point of failure should be avoided and low latency mechanisms are very desirable, so control action can be executed with fast responses.

In addition to these features, time information is a critical one because it is required to properly provide the interconnection of the different grid elements and guarantee its proper function. High accurate, reliable and scalable technologies to distribute time are required for next generation of Smart Grid networks. Typically, the higher accurate requirement for the time synchronization came from Phasor Measurement Units (PMUs). They are fundamental components in those grids and are significantly affected by the reliability of synchronization sources as GNSS systems. In fact, with a distributed implementation of PMUs in the power grid, the usage of the grid can be further optimized, however vulnerable to a loss or disturbance of synchronization. The IEEE recommends pursuing an alternative method using terrestrial systems as stated in IEEE Std C37.242-2013 "IEEE Guide for synchronization, calibration, testing and installation of PMUs for power system protection and control". This motivated the utilization/combination of solutions based on GNSS systems with wired time transfer solutions as IRIG-B and most recently, IEEE-1588 (Precision Time Protocol) based on Ethernet networks. Moreover, the guide specifies that the time tagging accuracy should be better than 1 µs (or equivalently 0.02 degrees of phase at 50 Hz). In current deployment most PMUs are already connected through network to a central control station where the phasor data is collected.

Our proposal approach is based on a modified PTPv2 protocol technology based on Ethernet optical fibers. The robustness of the fiber optic solutions is paramount for a robust, efficient power distribution grid. Furthermore, correct and reliable timing, at the nanosecond level solved by this research, is of great importance when implementing areas with demand-side-management, as planned in the Smart Grid most of the European Countries aim at. With specific modifications, time synchronization equipment for the PMUs can use the existing optical fiber infrastructure and the solution here presented can be of relevance importance for provide the scalability requirements provided by electricity market.

The highly accurate time provided by the solution here proposed is obtained with a minimum disturbation of data network bandwidth but imposing high priority to critical packets as timing ones. Because the Ethernet technology is not robust enough by itself, we use redundant ring topologies as to avoid single point of failures.

Widely used in power grid, the High-availability Seamless Redundancy (HSR) is a redundancy protocol for Ethernet (standardized as IEEE 802.3) networks. HSR provides zero recovery time in case of failure of one component. It is suited for applications that demand high availability and very short switch over time, for example, protection for electrical substation automation. On Smart Grid the recovery time of commonly used protocols like the Rapid Spanning Tree Protocol (RSTP) is not acceptable and therefore solutions implemented at the physical network level like HSR are necessary. Note that the ring-like topologies imposes as stringent latency requirement for the network devices that should implement optimized MAC controllers to guarantee that even using the ring topologies the whole latency does not increases significantly.

HSR was standardized by the International Electrotechnical Commission, Geneva, as IEC 62439-3 Clause 5. It is one of the redundancy protocols selected for substation automation in the IEC 61850 standard. HSR is application-protocol independent and can be used by most Industrial Ethernet implementations that use the IEC 61784 suite. HSR is typically used in a ring-like topology; however redundant connections to other networks are possible (such as a mesh topology). Our demonstrator will used as redundancy mechanism to guarantee packet delivery.

Another important element to be considered in the Smart Grid is safety, closely related with the previous features. The rapid growth of Intelligent Electronic Devices (IED's), Remote Terminal Units (RTU) and other components within electric networks is allowing Utilities to manage increased demand from users across the globe. However, the new technologies demand that safety standards be updated and modernized. Industry standards such as IED 61508 provide a roadmap for organizations that wish to deploy and support the new technologies of the Smart Grid. This standard is widely used by electronic device manufacturers and suppliers when any part of the safety function contains an electrical, electronic, or programmable electronic component and where application sector international standards do not exist. The IEC 61508 standard specifies the risk assessment and the measures to be taken in the design of safety functions for the avoidance and control of faults. In fact, IEC 61508 provides a complete safety life cycle that accounts for possible risk of physical injury and damage to the environment. Acceptable levels of risk are determined and procedures for residual risk management over time are established. In order to achieve the necessary Safety Integrity Level (SIL), the standard requires a proof of residual risk, which is based on the probability of dangerous failure. In this sense, the demonstrator will allow testing the impact of the integration of these intelligent systems in terms of safety and system latency in a network with high accuracy time synchronization.

This demonstrator integrates the inputs coming from WP1 regarding the determinism of the network architecture and the ones coming from WP4 focusing on enhanced QoS definition for critical data packets as timing ones. Furthermore, inputs from WP6 will take into account, in order to include the new methodology and tool, focused on safety aspects.

This Use-Case shall produce a demonstrator that illustrates the benefits and capabilities of the presented approach for Smart Grid applications. Benefits of this synchronized, low latency and deterministic networks as enabling technology for new applications or for improving development of existing ones will be shown. Also the integration of Smart Grid control devices (RTUs) with the safety tool (WP6), will allow us to analyse the impact, in terms of these features for multi-core embedded systems.

6.2 Description of demonstrators

The scenario for the demonstrator will be based on a real time Industrial Control System (ICS) of electrical substation. These control systems are critical to the operation of the Smart Grid and one of the main elements is the RTU. A RTU is an embedded system, composed of hardware and software components. There are several types of RTU: control units, communications modules and acquisition modules. Features such as synchronization, low latency and safety are critical in these types of systems. The structure of the demonstrator is schematically shown on next figure. It is based on the IEC-61850 division between the station bus and the Process bus (HSR). The target demonstrator includes one of the possible subsystems and integrates a ring topology to validate the proper operation of the HSR topology as well as proper mechanism of time distribution.

The minimum demonstrator elements required to validate our approach integrates one White-Rabbit switch with HSR capabilities, 3 networks nodes capable to provide transparent data networks access (both elements provided by Seven Solutions) and the RTU terminals (provided by Telvent). They can be connected to the switch and network nodes for network access but in addition the timing information can be provided from the Ethernet packets based on standard PTP protocols. In addition to this configuration and for those RTUs that do not implement PTP capabilities, we can connect the RTU timing interface by using specific timing ones as NMEA or IRIG-B. These different configurations are illustrated in the figure bellow by the utilization of different RTU colours although this is used just for illustrative purposes and the RTUs can be the same or different models.

For practical reasons, the demonstrator is limited to the number of elements here described but it can be significantly extended to illustrate the scalability of the solution here proposed. This scalability will be evaluated on the different partners' labs but it is out of the scope of the current demonstrator that will be presented in the framework of EMC2 activities.

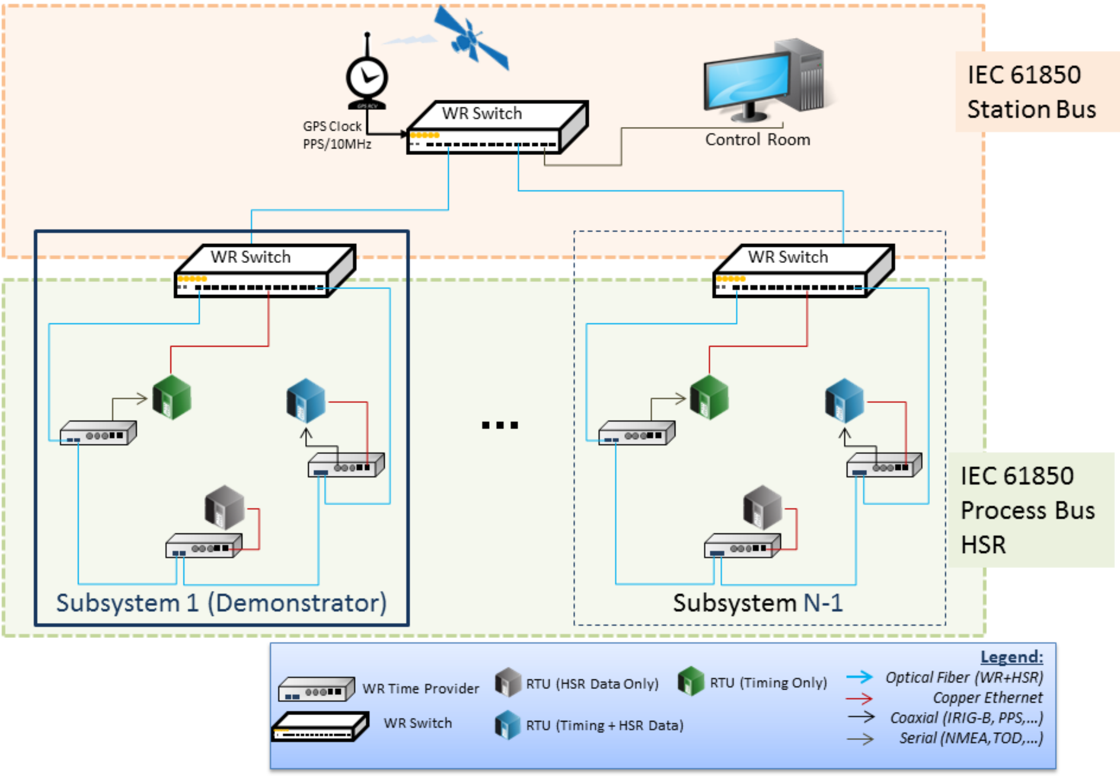

Figure 8: Demonstrator to be presented in the use case Synchronized low-latency deterministic networks

Note that target demonstrator is represented by the solid squared box in the left side but it can be easily scaled-up to illustrate more complex topologies. For practical reasons, current demonstrator will focus on this simple ring.

6.3 Requirements of the system

The current demonstrator inherits the requirements already addressed on WP1, WP4 and WP6. Because these requirements have been properly addressed and explained on those workpackets and for the sake of concretion, on this deliverable we focus only on the requirements strictly assigned to this use case. They are listed on the next table 2.

These requirements address three EMC^2 and energy domain topics. The first one is related with the effective use of the multicore processor for this market. The open possibilities of such devices allowing integration on the same devices much functionality with reduced power and enhanced performance. Moreover, if the proper critical design rules are followed and proper arbitration mechanism are used for the shared resources, multicore architectures allows the utilization on a single devices for mixed critically applications, reducing system power, space and cost. The effective utilization of these architectures for the Smart Grid market is here provided by Telvent`s RTU while the enhanced synchronization capabilities is provided by Seven Solutions.

The second requirement focuses on the utilization of a redundant network topology. This can be easily asserted by the ring-like topology of the demonstrator and significantly is related with the determinism of the solution here proposed.

Finally, the last requirement is related with the proper distribution of the high accurate time information. As commented this is a key property for many operations of the Smart Grid and particularly for the PMUs.

Table 2: High level requirements for the demonstrator of the Synchronized low-latency deterministic networks use case.

Requirement ID: <Participant>-<Req. ID>	Category <Functional / non-Functional>	Sub Category <HW, SW, …>	Short Description: <Req. Name>	Description: <Req. Description>	Verification Method <Description how to verify>	Rationale: <The rationale behind this req.>
HL-REQ-WP11-002	Non-Functional	Safety	Effective use of multicore embedded systems in the energy domain.	Enable the effective use of multicore embedded systems in the energy domain with special attention to synchronization and safety as defined in the relevant standards.	Validated in the use case UC11.5	Tackle challenges in the energy domain posed by multi-core embedded systems, by applying new low latency networks with high accuracy time synchronization, and safety concepts.
HL-REQ-WP11-005	Functional	System	Redundant topology networks based on HSR/PRP configurations.	According to IEC 62439-3 (High Availability Automation Networks - Part 3), Smart Grid networks should use redundant topologies Parallel Redundancy Protocol (PRP) y High-Availability Seamless Redundancy (HSR). Provided solutions should follows these protocols.	Verification of broken network links. This should not compromise data delivery or synchronization accuracy.	Smart Grid information is critical so we should avoid single point of failures in the networks.
HL-REQ-WP11-006	Functional	System	PMU/Synchrophasors time synchronization requirements.	According to EEE C37.118-2005 rules, the maximum tolerable error for Synchrophasors is 0.5º. This translates on a general requirement of synchronization accuracy better than 1us (following IEC-61850 recommendations).	Measurement of time synchronization errors using PPS / 10 MHz reference signals.	PMU are critical elements of the Smart Grid networks. Signals should be accurate on phase to aboit electrical issues.

The accomplishment of these 3 requirements will guarantee fulfilling the goal proposed in the framework of EMC² for this use-case and moreover the inclusion of relevant properties for the systems here developed.

6.4 Measures and indicators

The validation of the demonstrator here proposed includes many different elements. The most relevant are listed here. They are:

- Proper operation of the redundant network topology. This will be shown by a seamless operation of the different elements even on the case of opening the network ring.
- High accurate synchronization for the RTUs and critical Smart Grid elements as PMUs. This will be evaluated based on the PPS output of the different network elements (switches and nodes). Using a simple oscilloscope we can measure the synchronization accuracy.
- Zero-recovery time and low latency. Packet time-stamping will significantly help to achieve measures of network latencies and recovery time. Nodes will record this information to validate these premises.
- Proper operation of the control system in real time.
- Safety level for the RTUs

7. Abbreviations

Table 3: Abbreviations

Abbreviation	Meaning
3GPP	3rd Generation Partnership Project
API	Application Programming Interface
EMC^2	Embedded multi-core systems for mixed criticality applications in dynamic and changeable real-time environments
FITH	Fiber-to-the-home
HSR	High-availability Seamless Redundancy
ICS	Industrial Control System
IDM	Identity Manager
IED's	Intelligent Electronic Devices
IEEE	Institute of Electrical and Electronics Engineers
IET	Institution of Engineering and Technology
IETF	Internet Engineering Task Force
IoT	Internet of Things
KPI	Key Performance Indicator
OVA	Open Virtualization Archive
PLC	PowerLine Communications
PMUs	Phasor Measurement Units
PSTN	Public Switched Telephone Network
RFC	Request for Comments
RSTP	Rapid Spanning Tree Protocol
RTU	Remote Terminal Unit
SIL	Safety Integrity Level
SoS	System-of-systems
UWB	Ultra WideBand
W3C	World Wide Web Consortium
µC	Micro-Controller