PROJECT FINAL REPORT

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4 Final Report

4.1 Final publishable summary report

4.1.1 Executive summary

The project ^{flex}WARE (**Flex**ible **W**ireless **A**utomation in **R**eal-Time **E**nvironments) aimed at designing a novel platform providing real-time communication based on Wireless Local Area Networks (IEEE 802.11). A novel secure middleware between the physical communication and the application has been developed with special emphasis on security, flexibility, and support of mobile, real-time enabled nodes that can roam between the access points of the system. In conjunction with localization services this middleware provide basic technologies for building the dynamically reconfigurable factory of the future, seizing new market opportunities with revolutionary new possibilities for applications. The interfaces to the applications will allow third party development in a secure and predictable factory automation network.

The project addresses hybrid (wired/wireless) communication topologies, where real-time and reliable communication infrastructure is has to be guaranteed. The project provides solutions to the following open problems:

1. Localization of wireless nodes with an accuracy less than 1m in industrial environments
2. Clock synchronisation accuracy of wireless nodes with software timestamping under 1 micro second. Individual timestamp error for wired synchronisation with hardware support of less than 2ns.
3. Real-time communication with IEEE 802.11 using low-cost COTS WLAN hardware. Admission control and scheduling capable of handling flows within less than 15ms between request and acceptance of the new flow.
4. Seamless handover of roaming nodes maintaining RT communication within 50ms
5. Network and QoS management able to deal with RT communication
6. Scalable node design that allows to enable the use of resource-limited devices
7. A simulation tool able to cope with the complexity of industrial communication scenarios verified on a demonstration scenario and two smart warehouse scenarios.

The outcomes of the project open possibilities for more efficient production processes and plants due to flexibility as well as scalability like flexible production paths, sensors on moving parts through the whole factory, and mobile context aware control stations supporting maintenance in combination with location aware information.

It is foreseen that existing production facilities will benefit likewise from *^{flex}WARE,* regardless of the respective level of automation. The technology developed in the project is applicable to almost all use-cases in factory automation, enhancing production infrastructure in terms of quality and stability by gathering on-line process data in a revolutionary dynamic fashion. Moreover, the non recurring engineering (NRE) costs can be minimized and the production downtimes reduced to a negligible amount.

4.1.2 Project Context Summary and Objectives

To widen control over a factory from a purely wired to a wireless domain, both a secure and reliable communication infrastructure with real-time capabilities is needed. Such an infrastructure may be used to obtain flexibility within any stage of a manufacturing process, hence, enabling the development of revolutionary new applications. The international ^{flex}WARE (**Flex**ible **W**ireless **A**utomation in **R**eal-Time **E**nvironments) initiative established such a new infrastructure in order to fill this technological gap in the market.

The project aimed to develop a novel real-time communication platform based on WLAN. The developed novel, secure middleware between the physical and the application layer is designed with respect to secure, flexible and mobile, real-time enabled nodes in conjunction with localisation services. These services enable the dynamically reconfigurable factory of the future, opening new market opportunities with revolutionary new possibilities for applications. The interfaces to the applications are open, allowing third party development in a secure and predictable factory automation network. The project consortium has integrated a prototype system featuring the ^{flex}WARE architecture. Simulation results and measurements revealed the feasibility of the proposed system. More information can be found at the project website (www.flexware.at).

Project Goals

Figure 1 shows the project goals and a reference to other communication systems. The ^{flex}WARE communication middleware enhances existing communication systems in all three dimensions – real-time capability, scalability, and mobility. To achieve these goals special focus was set on a detailed requirements analysis and system specification. The ^{flex}WARE consortium has conducted an intensive background research with stakeholders in order to capture domain-specific knowledge and requirements that had to be integrated into the work packages of the project, and which placed con-

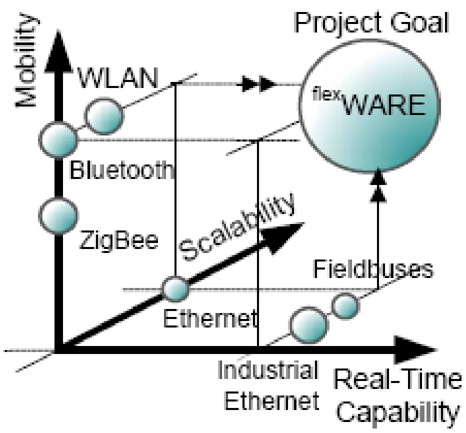

Figure 1: Project Goal

straints on the system architecture to ensure that integration takes place smoothly.

This system analysis yielded an extensive requirement list originating from different applications such as test of electronic devices in manufacture carts, automated guided vehicles and conveyors, smart warehouses, airport maintenance, or wireless terminals for robot cells. The requirements for industrial communication systems were grouped into general, system level, real-time, backbone, localisation, and finally safety and security requirements.

System Architecture

Based on these requirements a centralised three-tier system architecture (Figure 2) was selected, and three system components were identified to carry out the system tasks. The ^{flex}WARE node (FN) is the ^{flex}WARE component placed at the lowest tier of the system architecture. The coordination of the FNs and timely data transportation from end devices to the control room is carried out by the ^{flex}WARE access points (FAPs), which reside on the middle tier. FAPs are heavily involved in traffic scheduling within their respective wireless communication cells, so that real-time guarantees are met and QoS is not compromised. They also are involved in the localisation of all (moving) nodes on the factory floor and accommodate resources in case of seamless handover, if a FN moves from one cell to another. The ^{flex}WARE controller (FC) is the source which communicates with all the FAPs in the system to guarantee real time communication. With the help of high-precision clock synchronization and device management, it ensures real-time communication between the FNs and FC itself and also provides location information to all the FAPs. Handover of a node from one FAP to another is coordinated by the FC. The FC is also responsible for providing the interface between the ^{flex}WARE system and the real time backbone.

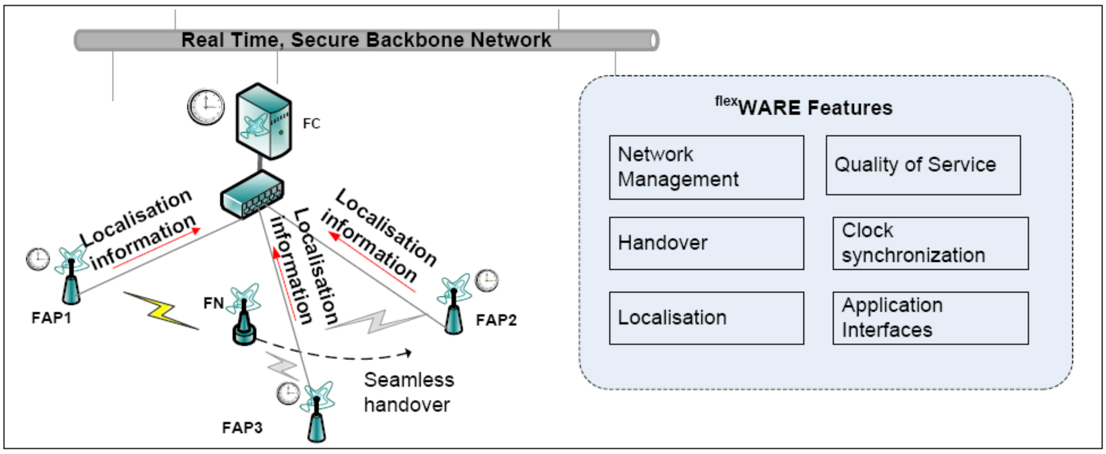

Figure 2: System Features

Aside from performing tasks individually the FC, FAP, and FN have to collaborate with each other in order to carry out new features of the ^{flex}WARE architecture like localisation, network management, etc. while preserving the system wide notion of QoS and real-time communication.

In order to address certain important topics, like medium access or the behaviour of ^{flex}WARE in the context of a large scale network, a task was solely dedicated to developing a suitable simulation environment. Through simulation, the possible ^{flex}WARE functionalities have been analysed and verified. At the end of the project the results from the different work packages were compared with the ones obtained from the simulator, enabling a calibration of the simulator. This makes the simulator a powerful tool for analysing scenarios where the ^{flex}WARE architecture is intended to be deployed.

Developed System Components and Tools

An important step in establishing a successful run-time QoS level, which is satisfactory for real-time flows, is an offline network design and dimensioning analysis. In this context, ^{flex}WARE had to deal with two main challenges - radio planning, and feasibility analysis for mobile nodes. The first challenge was addressed by the Wireless Simulation Tool (WST), a resource management tool, which implements an automatic access point planning algorithm that optimizes the number and positions of the FAPs. The second challenge was addressed through the development of an offline analysis methodology, based on information about the parameters of the real-time flows, network topology, and movement patterns of mobile nodes.

For the actual implementation of a middleware which is capable of assuring the required run-time QoS, the different requirements on the system were separated into distinct groups, which could be developed and tested individually. Each group consists of one or more modules, dealing with a specific part of the middleware. The overall functionality of the ^{flex}WARE system was partitioned as follows:

- Real-Time Communication (IEEE 802.11g), encompassing the modules
  - IsoMAC
  - Translation Unit
  - Admission Control
  - Traffic Scheduler
- Localisation and Handover (IEEE 802.11b), with the modules
  - Localisation
  - Handover
  - Resource management
- Clock Synchronization, involving both wired and wireless synchronization methods. This included the deployment of a Gigabit IEEE1588-2008 Transparent Clock and wireless synchronization using PTP (Precision Time Protocol).
- ^{flex}WARE Simple Node (FSN), which provides a reference hardware platform, built with low priced standard components, therefore sacrificing some of the real-time properties, but still fitting the needs of ^{flex}WARE architecture and industrial automation devices
- IT security lifecycle and safety model, which offers a reference model concept for supporting risk management and security design and implementation

Beyond the application development, the focus was also put on middleware integration. The strong cooperation of the consortium led to an effective feature integration, where the subsystems were not only put next to each other, but where additional benefits were created by a close interoperation of the individual subsystems.

Objectives Reached

The outcome of the ^{flex}WARE system was verified both, for the individual functional groups on their own, as well as for the whole system. In the following the key outcomes of the project and the capabilities of the developed are listed:

- Localisation: Time of arrival based methods have been used for localising WLAN clients in the project. To this end, PDoA and DTDoA methods have been used for localisation for standard off the shelf WLAN clients with varying density across the factory floor within an accuracy of less than 1 m.
- Handover: Fast handover schemes have been verified to make sure that the node does not loose connectivity whenever it roams from one FAP to the other. The verification shows that the handover takes place within 50 ms most of the time. In a few cases, the max threshold of

50 ms is breached, but by setting the watch dog factor accordingly, some cycle losses can be tolerated and hence handover times of 70 ms will not affect the performance of the system.

- Clock synchronization: The wired and wireless synchronization has been verified under various CPU loads. In the wireless case software timestamping is affected by high interrupt handling latency, but large latencies can be filtered out easily and the long term average offset remains under 1 µs. Wired clock synchronization achieved an accuracy of less than 2ns under any given network load.
- Resource management: The visualisation tool has been verified in the integration phase and the focus has been on verifying the radio coverage over the factory floor. For that matter, the fault-tolerance approach for achieving available radio coverage of the ^{flex}WARE system has been implemented and evaluated as a separated component in order to limit the complexity of the ^{flex}WARE system and its verification.
- Admission control and scheduler: The verification setup showed that under normal operating conditions, the time difference between the request of a new flow and its acceptance and inclusion in the schedule by the FAP takes only 15 ms, but it increases with the addition of new flows. The increase in time is caused by the increased size of the internal data structures and the consequently longer time needed to copy this data to the UDP message.
- IsoMAC: Major testing for IsoMAC included the verification of the timelines of uplink and downlink traffic. The result showed that the standard deviation for scheduling of this traffic in uplink and downlink direction is less than 4 µs.