A novel Approach for Flexible Wireless Automation in Real-Time Environments

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Abstract

To widen the control over a factory from purely wire based to the wireless domain, both secure and reliable communication infrastructure with real-time capabilities is needed. Based on wireless communication technologies, such infrastructures may be used to gain new flexibility within any step 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 establishes such a new infrastructure in order to fill this technological gap in the market. This paper gives an overview of the main ideas and the targeted goals.*

1. Introduction

The history of automation networks has shown the evolution from purely dedicated fieldbusses to Ethernet based technologies. ProfiNet [1] or Time Triggered Ethernet[2] are just two examples out of many. This step, of using technologies with origins in office IT domain, has nevertheless not taken advantage of wireless networks. However, the obvious increased flexibility of wireless approaches opens new possibilities for applications.

The main objective of the presented approach is to set up a networked, embedded control system, which is based on wireless technology, for the purpose of real-time factory automation. In particular, sensor and actuator nodes are enabled to co-operate with other wired or wireless nodes in the system. This is especially needed for tomorrows factories, where production lines are set up in a way that the path of goods through production machinery is not statically predefined. Consequently, existing production infrastructure will equally gain from the results of ^{Flex}WARE.

For example, to cope with quality issues caused by sudden parameter variations within the production path on any accessible point, information has to be gathered as fast as possible. This information, of course, has to be tightly time correlated with any existing process data. To this end, the only feasible way to enhance the process monitoring capabilities is by adding wireless data collecting nodes.

Using ^{Flex}WARE this can be done without altering existing infrastructure. The aim is to define a platform that fulfills the requirements of flexible wireless communications. The vision of the developed platform is to create a turnkey system that can overcome the restrictions of the state-of-the-art wireless real-time systems, which are bounded to single cell network. The proposed concept is shown in figure 1.

The infrastructure relies on a real-time backbone network. However, the backbone network is out of the scope of the proposed research and is considered to comply with the respective real-time Ethernet standards (RTE). Nevertheless, real-time controllers (e. g., the valve controller in the lower right in figure 1) rely on deterministic data communication capabilities of the backbone network. Interaction between this generic backbone network and communication controllers requires an interconnection that is capable of re-scheduling real-time communication between domains in case of changes in the network topology. An instant of this would be when a mobile node, such as an industrial cart carrying production goods i, roams from one cell of the communication network to another inside the plant. For the mobile part of the proposed sensor/actuator platform, IEEE 802.11 [3] wireless LAN is one of the most promising communication standard to augment wired Ethernet.

After this introduction this paper will present a short analysis of the state of the art. This will be followed by a detailed description of the proposed approach. This system architecture logically leads to the communication stack, which should be able to deal with localisation services, network management and safety and security features, which are described after the system concept in section 4. A conclusion and outlook to further work will round off this paper.

2. State-of-the-art and User Requirements

The idea of using wireless technology to tunnel fieldbus networks was already presented in the RFieldbus

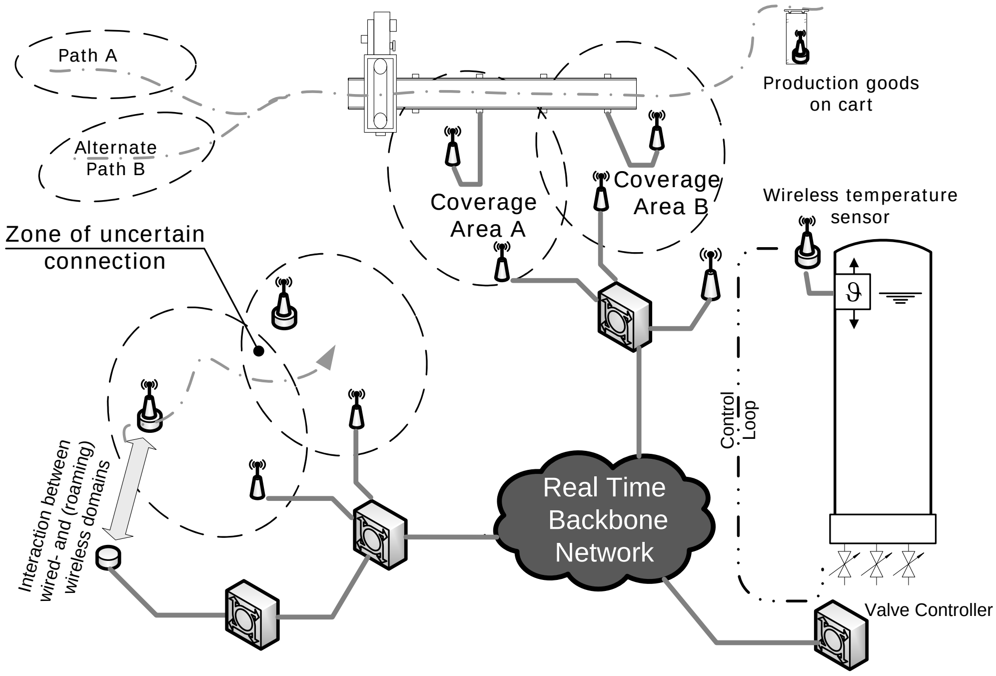

Figure 1. Proposed system concept, the boxes connected to the Real-Time Network are conidered as real-time controllers which are enabled to do the traffic scheduling in both, the wired- and the wireless domain.

project [4]. In this approach WLAN technology is used to tunnel the PROFIBus protocol via WLAN. The biggest advantage of having a wireless network is the resulting freedom of mobility. Unlike the restrictions imposed on the users having wired connection with the network, WLAN users can easily change their position within a certain range. One essential problem with 802.11 [3] is that the standard does not define roaming between multiple access points. Hence, the IEEE published a recommendation named 802.11f[5], which defines fast roaming for nodes between access points using the Internet Access Point Protocol (IAPP).

Actually both, wired and wireless networks, have their pros and cons. The biggest advantage of having a wireless network is that one does not need to install cables and can move within the supply area without worrying about necessary infrastructure. Further, it is possible to dynamically add nodes to the shared medium. Thus, the network offers some flexibility when it comes to the number of nodes that have to be supplied with a network connection. Certainly, this is only valid within a limited range due to the fact that all clients share a limited bandwidth on one access point.

Wired networks on the other hand can provide very high data rates which wireless networks can not support because of bandwidth limitations and unavoidable transient disturbances on the channel. Furthermore, it is easier to provide certain security measures due to the fact that access to the network can be controlled by restricting physical access to the media.

Nevertheless, the simplicity with which a WLAN can be deployed and used provides a big incentive for WLAN users. The IEEE 802.11 [3] standard governs the working and operation of WLAN. It is part of the IEEE 802 working group which deals with local and metropolitan area networks.

3. System Concept

The particular strength of the proposed approach is the intrinsic ability to cope with complexity of multiple wireless access points. Moreover, the inclusion of localisation services allows the monitoring and prediction of paths of mobile nodes and therefore copes with spatial uncertainties to schedule more efficient handover. For these distinct additional services to become part of todays wireless networks, a high-precision clock synchronization within the whole network is mandatory. Also, temporal uncertainties may be reduced to a minimum due to a system wide notion of time. For the sake of completeness, it has also to be mentioned that clock synchronization within the whole system is needed in order to ensure that real-time requirements of a factory automation system are met. Moreover, this real-time implementation will ensure bandwidth guarantees for all nodes as well as safety and security features.

Equally important is the focus on middleware in the proposed concept. As will be described in the next paragraphs, the vision is to establish a wireless infrastructure independent from actual communication technologies used. This objective will be reached by the development of a middleware coping with dynamic reconfiguration of the network topology due to nodes travelling between different access points in the system. Additional challenges are to design this middleware as secure as possible yet ensuring real-time, QoS (Quality of Service) aware behaviour. In the case of automation of manufacturing systems, these distinct features enable technologies for further use of such systems and will be therefore mandatory in the system architecture.

3.1. Flexible production paths

The introduction of wireless real-time networks provides flexible factory automation with varying paths of production goods, that are neither clearly defined nor fully predictable in advance. For example, in case of production machine failures, production paths most likely have to be re-arranged on short notice requiring a flexible mean of changing the flow without extensive reconfiguration.

Large industrial facilities, being the case in automotive industry, already use flexible infrastructures where whole production units can be replaced transparently in case of failure of other units. Yet, this approach severely limits their real flexibility and increases the amount of work in case of a replacement. The ^{Flex}WARE approach will overcome this limitation with a factory-wide wireless real-time communication structure.

As it is not reasonable to assume that a single radio cell can handle a whole factory, the different paths a production good may take as described above will be, in general, mapped to multiple cells. This prerequisite consequently leads to the infrastructure having to cope with travelling nodes distributed throughout the entire system, yet guaranteeing that communication can be done in real-time with any remote controller over a multi-cell WLAN.

3.2. Roaming between wireless domains

In a harsh industrial environment, it is unlikely that an access point in a network is sufficient to provide communication access for hundreds of mobile real-time clients. Such a network has to be capable of hosting multiple domains, allowing all mobile clients to select those providing the best services. Consequently, this requires the network infrastructure to transparently switch between access points. To implement sufficient flexibility, the communication controllers have to interact in order to organise this roaming between domains. Moreover, roaming of real-time wireless networks can be supported by location awareness of the nodes, in order to pre-schedule the handover from one domain to another, when a node approaches a zone border. For that reason, the proposed infrastructure has to have location awareness features. Among the many approaches for location awareness, a technique, that can detect nodes in terms of differential delay measurements inside the access points is chosen. Details on this approach are described in a later section 4.1 in this paper.

Figure 1 shows an example of a mobile node that has to co-operate with a wired sensor in order to fulfil a given task. The figure shows how real-time communication has to be ensured not only in the wireless domain, but also in a backbone network while the nodes are on the move.

3.3. Network-Based Control

Another aspect to take into consideration are network based control and servo loops of an automated production system. In factory environments, a co-operating group of both wireless and wired subsystems has to fulfill control tasks beyond physical layer borders.

Figure 1 shows a control loop, where a process variable has to be gathered at the (mobile) surface of the tank. Data for this control loop is routed over a wireless link, the backbone and the valve controller. Thus, to guarantee real-time requirements, communication controllers have to negotiate the respective QoS parameters and implement them (e. g., through synchronized timeslots) for guaranteeing the functionality of the control loop.

Of course these timing guarantees for data transfer have to be met even when the mobile sensor or actuator is moving and/or roaming. Roaming may not only be triggered by movement but also by sudden changes in the rough industrial environment causing the wireless connection between a node and the respective access point to deteriorate (e. g., moving large metallic objects within the factory). In either case, communication controllers have to provide sufficient resources in all neighboring cells or support immediate re-scheduling of resources in order to guarantee the required communication parameters even under unpredictable behavior of the environment.

4. Communication Stack Concept

The system concept directly leads to a communication structure depicted in Figure 2. The main focus in this approach is to rely as much as possible on commercial of the shelf communication stacks.

4.1. Localisation Services

The concept is based on the principle that messages from one node can be monitored by more than one access point. A mobile node transmits a packet via WLAN, which is received by at least three access points which are synchronized with each other. Using the timing information either one station can calculate the position of the mobile node by knowing the position of each receiving access point and at least three propagation delay differences. This is done using the propagation speed of the electromagnetic waves in air. To cope with reflections and multi path transmissions, the number of receiving stations can be increased and obviously unreasonable measurements dropped. This concept relies on the work presented in [6].

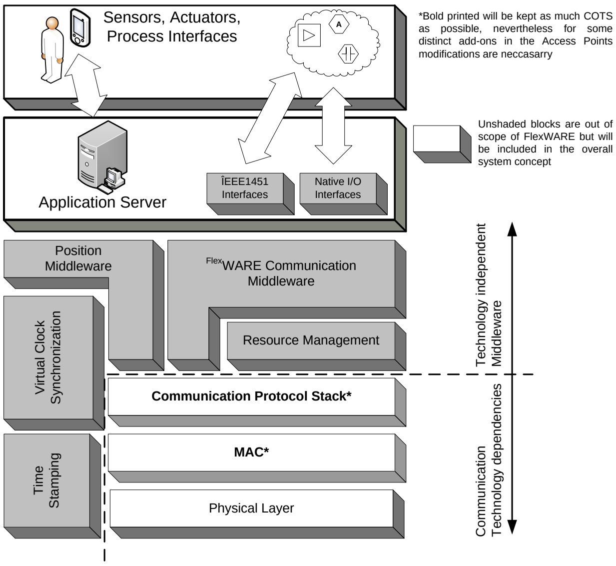

Figure 2. Structure of the $^{\text{Flex}}$**WARE system**

4.2. Network Management

Management of such smart infrastructure is crucial for industrial acceptance and commercial success of such system. In addition to providing functional communication, such a system needs to provide means of managing its infrastructure. Since the backbone network is out of the scope of this project, infrastructure management has to cover the following entities:

- Real-time communication controllers: Issues of scalability and lack of real-time bandwidth have to be reported by real-time controllers. Hence, management of inter-real-time controller communications has to be ensured.
- Control and Provisioning of Wireless Access Points (CAPWAP): Access points have to be supplied with the respective access lists, frequencies, and bandwidth alarm thresholds that are specific to real-time requirements and their remaining configuration. This and the means for monitoring and logging have to be provided by a management system.
- Wireless nodes: As in the entities above, management of wireless nodes has also to consider real-time requirements of the system.

4.3. Safety and Security

In industrial automation safety functionality and the respective safety protocols are usually implemented at the application layer. The underlying communication is considered as black or gray channel. As the safety application defines a cyclic data exchange, the underlying communication should work on a cyclic base as well with a communication cycle clearly faster than the safety application cycle. When receiving a special command, e. g., from an emergency stop switch or if no data are received after a predefined time the safety application enters its predetermined safe state. Since wireless communication is clearly more unreliable than wired communication it is per se not well suited to be used as communication channel for safety applications. The risk that the system often switches into safe state as a result of a fault on the communication channel is pretty high. By extending wireless communication with cyclic communication as proposed in this project, the applicability of safety protocols within wireless - including mobile - systems will be improved essentially, since time-slot technology makes communication deterministic and far more reliable. This enables completely new opportunities and will help to further reduce industrial accidents.

5. Conclusion and further Work

This paper presents an approach to bring state of the art office wireless network technologies to the factory floor. Although various other approaches exist, the novelty of the proposed concept is to include technologies like IEEE802.11f for inter-access point communication, location based services or network management approaches together with real-time approaches for wireless LAN.

This approach is demonstrated on the basis of a concept and will be further investigated in the international project $^{\text{Flex}}$WARE. Next steps will be extensive investigations on the system concept and implementation of laboratory prototypes, which will be tested in a industrial factory automation testbed.

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