Wireless Networks in the Process Industry: Opportunities for Ultra Wideband Applications

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Abstract—**The advances in mobile technology, such as ultra wideband (UWB), enable the usage of advanced applications in the process industry. The main challenge in the first phase of designing UWB networks and applications is getting to know what the potential customer, e.g. process industry, wants. In this paper we present how to apply a user requirements elicitation process to get information about the expectation from the process industry regarding wireless networks and more specifically ultra wideband. This paper describes the design process of the balanced decisions that have to be made regarding applications as demanded by the process industry, and the technology as offered by the ICT industry. The outcome of this feasibility study leads to the decision for going on with the next step, i.e. the design and implementation of UWB applications in an industrial plant.**

Index Terms—**process industry, ultra wideband applications, user requirements, wireless networks.**

I. INTRODUCTION

THE emergence of commercial wireless devices based on ultra wideband radio technology (UWB-RT) is widely awaited and anticipated [1]. UWB engineering efforts started already in the end of the 1970s but were recently boosted because the Federal Communications Commission (FCC) allowed UWB-enabled devices to overlay existing narrowband systems [2, 3]. A growing interest within the wireless industry as well as within academic and other research institutes in the US and in Europe can be noticed [1]. The regulation by the Federal Communications Commission (FCC) and the European Commission (EC) is still in progress but nevertheless the question 'which will be the so-called "killer" application' has presented itself [e.g. 2]. We argue to follow a design approach instead of waiting on accidentally discovered killer applications and started a research program to design UWB applications.

UWB can be applied in different domains; the process industry opens up interesting possibilities. The research presented in this paper concerns a feasibility study for novel UWB applications in the process industry. Firstly, meetings with stakeholders of this industry led to the impression that characteristics of the UWB technology suit their environment quite well. However, since the technology is new and not proven yet it is not possible for the industry to explain their wishes and requirements. This is an ever returning issue in situations when new technologies are rising. Furthermore, a network of actors is involved in the development of UWB applications. A consortium of partners with their own know-how and expertise is needed for a design project such as this. In the design project, all the time trade-offs have to be made between the technology, the user requirements and the organizational issues. In this paper we describe the first phase of these trade-offs, i.e. the analysis phase of the design process. The result of this phase should consist of letters of intentions with partners who want to participate in the project, an overview of the technical options and a rough description of an application.

The paper is structured as follows. We begin with a brief overview of the design activities based on theory. In particular, we look at the design activity for user requirement elicitation. Next, we present the case study by describing the setting, UWB RT technology and the UWB applications requirements for the process industry. This is followed by an analysis and we end with final remarks.

II. DESIGN ACTIVITIES

Asking potential customers for their wishes with regard to applications which are out of the scope of the normal operation, is a real challenge. In earlier research Den Hengst et al. [4] found that Group Support Systems (GSS) can be used to design a repeatable process for user requirements elicitation. Group Support Systems (GSS) are designed to improve the efficiency and effectiveness of meetings by offering a variety of tools to assist the group in the structuring of activities, generating ideas, and improving group communications [5]. Den Hengst et al. [4] proposed the following repeatable process for user requirements elicitation.

- **Participants to invite.** Selecting and inviting the participants is the first step for analyzing user requirements. GSS have been found to effectively support large groups (more than 8 members) [6]. The participants need to be reasonably knowledgeable about the topic and should be interested in talking about it. They should be comfortable in talking to each other, but over-familiarity might have a negative effect on the

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results. Furthermore, the group should not include too many different types of people.

- **Basic meeting activities.** Briggs et al. [7] have identified seven basic activities in a group process: divergence, convergence, organization, elaboration, abstraction, evaluation and building consensus. These basis steps are used to design the design process and compared with literature on focus groups [8]. Concluded, the steps to be carried out are: (0) warm-up, (1) problem analysis based on current daily experiences, (2) solution generation based on those experiences, (3) demonstration of future scenario's, and (4) redefinition of solutions based on this.
- **Techniques to use.** Briggs et al. [7] propose ThinkLets as an approach to produce far more predictable and repeatable results of group sessions. Thinklets describe in detail how a certain activity can be realized. To come up with the key problems of the participants, three thinkLets are used: FreeBrainstorm (Divergence), FastFocus (Convergence), and BroomWagon (Convergence)[1].

Prior experience has shown that three hours is a suitable length for these kinds of sessions [8]. Den Hengst et al. [4] calculated that this user-requirements-elicitation GSS session takes about 3.5 hours based on a group size of fifteen participants. With more or less participants, the time schedule should be adapted. Based on the output of the GSS sessions and the analysis of the existing applications, professionals add their knowledge, expertise and creativity to develop storylines. Model techniques originating from product design theories are helpful here.

III. Case: a Feasibility Study for UWB applications

The start-up firm Utellus (www.utellus.nl) started its business to develop protocol stacks for mobile ad hoc networks. Together with the Delft University of Technology (www.tudelft.nl) they performed a feasibility study to investigate whether and how UWB applications can be developed. This feasibility study took place between September 2004 and April 2005.

A. Setting

The first step in the process to design UWB applications was a meeting of the startup firm Utellus and research from the Delft University of Technology to discuss the idea to submit a proposal for getting subsidy for a feasibility study to design UWB applications. Knowing roughly the characteristics of UWB technology led to the idea to focus on the idea to develop UWB applications for the process industry. The actor scan pointed at the investigation of the wants and the needs of the process industry for wireless applications. The involvement of the users/customers from the process industry, varying from plant managers of a batch factory to automation engineers, forms a necessary condition for a successful feasibility study. The mentioned partners (Utellus and faculties of TU Delft) decided to cooperate in the feasibility study and to involve industrial partners from the very beginning of the study.

We found that communication networks are widely used for automation purposes in the process industry. They are the subject of rapid developments in technology and software. The choices for the architecture of the automation profile can be different: in some cases the local area networks between office and factory make sense; sometimes integrated distributed control systems are preferred over simpler more decentralized personal-computer-based systems. Modern automation systems provide possibilities for fitting the combination of centralization and decentralization, so this combination is often the best choice. The industrial automation field has recently experienced the adoption of wireless networks solutions in these systems [9, 10].

In particular the areas of Manufacturing Execution Systems (MES) and Control Systems are expected to be the most promising opportunities for wireless application for the communication networks in the process industry. MES consist of plant-wide information systems providing information that enables the optimization of manufacturing activities from order launch to finished products. Control Systems are usually hybrid hardware/software systems such as DCS (Distributed Control Systems), PLC (Programmable Logic Controllers), SCADA (Supervisory Control and Data Acquisition) systems and other computerized process controllers. For each MES or Control operational function there is a range of feasible automation degrees. In principle, zero percent automation and one hundred percent automation hardly exists. The level of automation depends often on the type, age etc of the industrial plant. For example, it could be difficult to operate a (small scale) multi-purpose batch plant at a high level of automation, as several operations may be carried out in the same equipment, and the same operation may be performed in different types of equipment. One-to-one mapping between equipment and operations does not exist there. For this batch-wise type of industry, where flexibility is an important issue, wireless communication can be an appropriate solution.

B. UWB RT Technology

The occasion of this feasibility study is the rise of a new technology, i.e. Ultra wideband radio technology (UWB RT), and in that sense it is a technology push project. UWB belongs to the family of the wireless networks together with radio technologies within the IEEE 802 family and Bluetooth [see 11 for an overview].

Comparisons in Foerster et al. [3] indicate that the *spatial efficiency* of UWB systems (estimated at 1 000 000 bits/second/square meter) far exceeds efficiencies of systems based on the IEEE802.11a Standard (estimated at 83 000 bits/second/square meter), Bluetooth (estimated at 30 000 bits/second/square meter), and the EEE802.11b Standard (estimated at 1000 bits/second/square meter). Capacity

[1] Due to space constraints we refer to Briggs et al. [7] and Den Hengst et al. [4] for a description of the thinklets.

calculations for AWGN-UWB channels support this assessment [2]. Porcino and Hirt [11] conclude that "UWB-RT has the potential to become a viable and competitive wireless technology for short-range high-rate WPANs[2] as well as lower-rate and low-power-consuming low-cost devices and networks, with the capacity to support a truly pervasive user-centric and thus personal wireless world".

After we scanned the available and usable technologies and after we understood to some extent what the industry wanted we started to make a first overview of the functional design decisions. On the basis of our study of the future demands for communications in the process industry, one may conclude that the sector does have a huge interest in new radio technologies offering opportunities for "freely moving", very low power wireless communications. The application for such new radio technology will be in "indoor plants" as well as on open air wide-area factories and industry plants. Basically the new communications must satisfy the following demands:

- Support of communications of persons or groups of persons active in the plant at any place or any location. In addition there can be a centralized control on the communications.
- The new technology must be a vehicle for a new generation of ubiquitous wireless, telemetric communications, offering possibilities to connect sensors and actors on a flexible (plug and play) basis using flexible 'ad hoc communication'.
- The system must have sufficient performance (bandwidth) to support applications such as visualization of data (e.g. measurement data, process information, showing pages of instruction manuals).

Based on investigations the technical experts proposed that the new system concept should meet the following constraints:

- low power transmission in combination with high data rates,
- efficient and effective usage of the available bandwidth – we propose a simplified multi-band system capable of handling the diversity present,
- usage of multi-hop techniques to facilitate the combination of low power with higher data rates,
- low 'electronic complexity' yet full utilization of the available bands,
- adoption to specific facilities on the physical layer,
- meeting future accepted UWB standards,
- capable of good time resolution, in particular with respect to the features for localization of transmitter nodes or transponders in the communications network.

There are two kinds of UWB-RT standard proposals, namely impulse-radio UWB (IR-UWB) and multi-band UWB (MB-UWB). In IR-UWB, very short pulses are sent over the channel, and the information is modulated on the delay and/or the amplitude of these pulses. In MB-UWB, on the other hand, the spectrum is divided in a number of smaller bands; where in each subband the conventional Orthogonal Frequency Division Multiplexing (OFDM) modulation scheme is adopted. IR-UWB is easier to implement than MB-UWB. As a result, the power consumption is generally lower. On the other hand, MB-UWB can generally achieve higher data rates than IR-UWB, due to the efficiency of the OFDM modulation scheme. The major problem with implementing an IR-UWB system is synchronization, whereas the main problem related to MB-UWB is the need for accurate and fast (hence, expensive) A/D and D/A converters. Current research projects aim at solving these problems in an effective way.

The conclusion of the UWB-technology scan is that it can play an effective role in the telecommunication and telemetry needs in this specific application area. In addition we were able to conclude that UWB can offer extra facilities not offered by current available techniques. The aimed advances of UWB are: 1) low energy, 2) localization features and 3) realization of flexible infrastructures.

C. UWB applications for the process industry

An important activity in the research was a GSS session to get more insight in the wants and needs of the process industry regarding wireless networks. The objective of the group session was twofold. First, we wanted to know in what kind of situations the customers foresee advantages of wireless networks. We did not ask the customers to come up with wireless applications since not every potential customer knows about the technical possibilities of wireless applications. Instead we asked them for the areas that they currently encounter in the process industry as potential areas to use wireless networks. A prioritization of these areas should give insight in the potential use of applications on wireless networks. Secondly, we wanted to know what criteria potential customers use for selecting a certain application for these areas by elaborating on the effect of the possible applications by means of UWB technology. We described the session by specifying the participants we invited, the activities and techniques we used, and the results.

The participants to invite. The fourteen participants were people working in instrumentation and automation departments in the process industry and their suppliers. Four researchers involved in the feasibility study were present to provide extra information if needed. They did not actively participate in the brainstorm session. The participants were selected based on their knowledge, interest, representing a wide range of companies from the industry and their suppliers and willingness to participate. Access to these participants was provided by personal contacts of Utellus, the researchers, and the 'International Instrument Users' Association' (WIB; www.wib.nl). This is an organization that evaluates process instruments for their members. The chairman of WIB was also present at the GSS session. The invited process industry participants had functions like plant

[2] WPAN is Wireless Personal Area Network (IEEE 802.15.3)

manager, instrumentation or process automation specialist and worked in companies from the chemical and food industry, i.e. Shell, Dow Chemical, Dupont, Exxon, Heineken and Unilever. Participants from the process industry suppliers were equipment builders and project managers for plant building from companies, i.e. Enraf, Controlec and Produca.

The activities and techniques used. The session was to a large extent structured conforming the GSS session for user requirements elicitation [4]. The outline of the session is presented in Figure 1 and below we describe what we did including how it deviated from the original outline.

- The brainstorm started with the question to spout ideas for wireless network opportunities (see FreeBrainstorm to identify opportunities for wireless networks in Figure 1). This means that there was not first an activity to select important problems and then brainstorm about solutions on the problem but that we immediately started with the solutions. The reason for this is that the participants were experts who are looking for specific solutions. However to keep an open mind we explicitly asked about wireless networks opportunities in general and not for UWB technology specific in this phase of the process. The participants typed about 200 ideas of which 28 were left after the convergence activity (Fastfocus in Figure 1).
- After formulating the 28 most important opportunities we did a divergence activity that was not in the original scenario. The participants were asked to formulate reasons why these 28 opportunities were important for them. We did this extra activity because the project team members wanted to have this extra information for the requirements analysis (Leafhopper in Figure 1).
- The participants voted for the x most important opportunities after this extra divergence activity and before the UWB presentation (BroomWagon in Figure 1). Nine ideas got four or more votes. Two of them could be combined so we ended with the seven most important opportunities for wireless networks in general.
- A presentation on the features of UWB followed with examples. Questions of the participants on the promising functionalities were answered by practitioners from Utellus as well as researchers from the university.
- In pairs of two the participants elaborated offline on the context, idea of the application and effect of the application for the top seven opportunities (Offline activity in Figure 1).

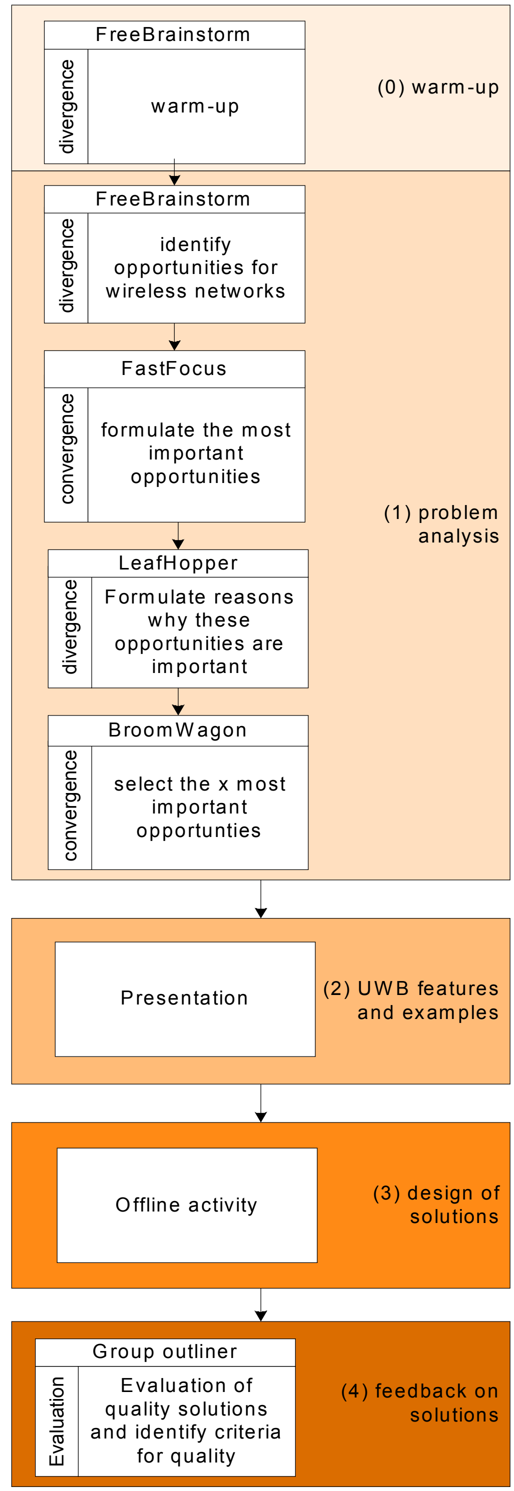

Fig.1 Layout of GSS system

- The solutions were presented and during these presentations the other participants and the experts typed in the GSS system their comments and ideas (Group Outliner in Figure 1).
- The session ended with an evaluation.

In total the session took four hours.

Result of the session. The seven most important opportunities that were worked out into solutions by the participants are the following:

1) automatic registration and localization of persons
2) installing temporary measurements: pilot plant
3) communicating of sensors with control systems including on locations with long distances
4) tracking and tracing including quality control (inline)
5) mobile tool for operators to monitor and have remote-access to central databases
6) measurement and steering of rotating equipment
7) measurement data from unsafe zones to safe zones

The above-mentioned seven applications were further discussed with experts and the application notions were sharpened and clarified. Firstly, we organized a discussion event to present and discuss the outcomes of the GSS session with participants and other representatives of the industry. Secondly, we did five in-depth interviews with participants of the session representing the chemical industry, the food industry and the suppliers. Based on that we further fine-tuned the applications; a summary of this can be found in the first column in Table 1.

IV. Analysis

The analysis of this case study focuses on 'how can we get the enabling technology to support an application that fulfils the demand of the users', i.e. the process industry.

The research aim was to gain an insight into the industrial view with respect to the current wishes and more future-oriented expectations regarding wireless applications in the process industry. Next, the industrial needs in relation to wireless applications, as formulated by industrial experts - in the literature, during the GSS session and interviews - are commented on by the experts in the field of the UWB technology. In Table 1 the applications are marked in the 'Fit' column: the very promising applications are marked by "++', the neutral applications with "0", and the not appropriate applications with "—". Applications marked with "?' still need additional research to specify matching.

To summarize, two applications look most promising (C and D), two applications look promising (A and F), one needs further research to be able to draw any conclusion since some expert opinions are very enthusiastic but the UWB fit is not clear at all (G), one is neutral (B) and two do not seem interesting at the moment (E and H). An important remark is that UWB is only interesting for wireless applications A, B, D and F if the network is covering the whole area.

TABLE I
MATCH DEMAND AND TECHNOLOGY

Possible Application	Wireless alterna-tives	What are the pros/cons of UWB w.r.t. these alternatives?	Fit
A1. Automatic registration and localization of persons	RFID, WIFI, GPS	UWB has a high resolution and good penetration in materials, in contrast to other techniques. Due to the simplicity of an UWB	+
A2. Automatic registration and localization of assets (machine parts, equipment, moving objects)		transmitter, UWB also allows for low-cost tags. The reader could be rather expensive though. Existing RFID technology also consists of low-cost tags and a high-cost reader, but it has a rather limited range (a few meters). WIFI has a good range but is less accurate than UWB. The WIFI transceivers are also rather bulky and power hungry. GPS, finally, does not have a good indoor performance and is rather expensive. The ad-hoc nature of UWB also allows for a distributed knowledge of the location of the different persons.	
B. Tracking and tracing of products - (inline) quality control	RFID	RFID might also be a good solution here, since we can place detectors on the route where the products pass, and the distances can be kept small. However, if the tags need to transmit quality information, we require some type of active RFID, and UWB might be a possible solution for that.	0
C. Rapid commissioning of process control equipment – in particular in pilot plants.	WIFI	The radar-like localization capability of UWB makes it possible to detect where the sensors are located. WIFI also has this ability, but the accuracy is smaller. Furthermore, the large spatial capacity of UWB (more than 1000 kbps/m^2) allows for the presence of many temporary sensors in a small area. WIFI has for instance a capacity that is less than 100 kbps/m^2. The UWB tags are also very cheap, much cheaper than the WIFI tags. Finally, the ad-hoc nature of UWB, will allow us to seamlessly remove or add sensors to the network.	++
D. Remote control. Plant wide communications not related to process control. Secondary sensor & control networks like gauging in tanks, safety controls, piping, fire security and so on.	WIFI, Bluetooth Conven-tional radio systems.	It is known that UMTS and WIFI have a larger range than UWB. However, their data rate is a bit lower, and the related sensors would be more expensive. Bluetooth has a similar range than UWB. Relaying/hopping could be used to bridge larger distances, since it is expected that many wireless terminals will be spread out over the plant. Moreover, route diversity in such an ad-hoc network creates robustness against defect terminals or unforeseen obstacles. Due to the large bandwidth, UWB is also more robust to multipath propagation than other systems. This could be important in an industrial environment.	++
E. Point-to-point communica-tions over long distances	Public network, fixed lines, micro-	Conventional communication systems with a large range, e.g., UMTS, are better suited for this application.	-

	wave, satellite, fixed.		
F. Mobile tool for operators to monitor and have remote-access to central control room (CCR) systems	Conven-tional radio systems, WIFI.	UWB can offer the highest data rates, but as discussed in application D, its range is rather limited. Hence, an ad-hoc network deployment is required to set up a connection over larger distances. UWB can also offer accurate localization, so the data that is available to the operator can be made location dependent. Due to the high bandwidth, UWB can also benefit from the large multipath diversity of the channel.	+
G. Measurement and steering of rotating equipment	No.		?
H. Measurement data from unsafe zones to safe zones	No.	Currently, only wired solutions are used for this type of application. The advantage of UWB for this application would be the low sensor cost and the large robustness against multipath fading. However, the high peak energy of pulse-based UWB systems could make this system more unsafe than existing wireless technologies.	-

V. Final Remarks

Based on the results of the GSS session, interviews with industrial companies and the literature study it can be concluded that the promising applications, although not yet clearly lined-up, are sufficiently obvious to urge the process industry and the developers of UWB application to continue research on them and start demonstration projects. The expectation is that a hybrid form of technologies will be most rewarding. At this moment we are in the final stage of agreement with one of the industrial participants of the GSS session to start implementing UWB applications in a pilot setting on one of its chemical plants.

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