Bluetooth in Industry

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I. Introduction

BLUETOOTH in industry impose new requirements on the technology, while it at the same time opens up new and interesting possibilities for using wireless communications in industrial applications. This paper will discuss some of the issues which should be considered in order to utilise Bluetooth in industry.

The first section is a brief introduction to wireless communication in industrial environments. Results from a field test at Väröbruk Chemical Pulp factory Sweden will be discussed. The second section will discuss Bleutooth in industry, what possibilities and limitations are there. The third section discusses the industrial requirements on Bluetooth, which are somewhat different from the requirements imposed by the office automation market. The last two sections provide information about ABB's experience with Bluetooth, and Bluetooth utilised in ABB's new industrial controller.

II. Wireless Communications in Industrial Environments

A. Received power as a function of receiver location

Mapping of received power reveals how received power depends on receiver location provided a fixed transmitter. Received power depends on distance between transmitter and receiver, fading and reflections. In indoor industrial environments the received power attenuation due to transmitter/receiver separation will be slower than in outdoor environments due to radio wave reflections from machinery made of metal.

Received power was measured at a number of locations along the two different paths named Path 1 and Path 2 (see Fig. 1). At each measurement location, the received signal was averaged over approximately one wavelength.

The transmitted signal was a continuos harmonic wave at 2.45 GHz. Output power was 20 dBm. A spectrum analyser with 1 MHz resolution bandwidth was used to measure the received signal. 3 dB omnidirectional antennas at height 2.8 and 1.8 meters above the floor where used for Tx and Rx respectively.

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B. Chemical pulp factory

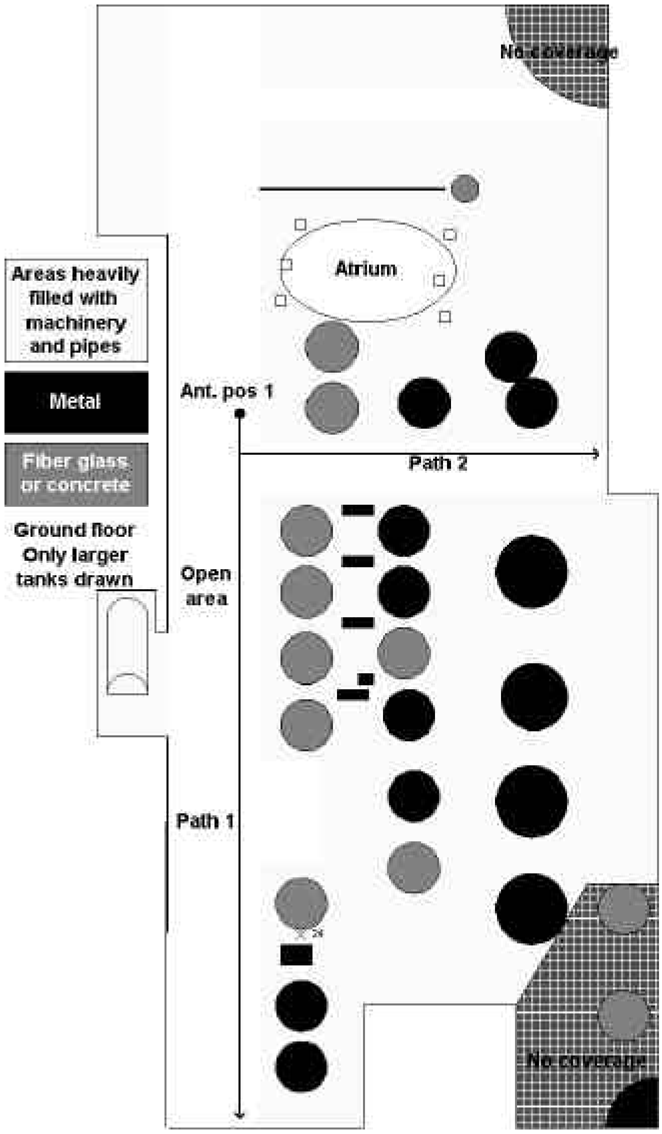

Fig. 1. Floor plan of the chemical pulp factory; ground floor

The measured received power vs. logarithmic distance between Tx and Rx at several positions along Path 1 are plotted in Fig. 2. Path 1 follows a corridor radial to the Tx antenna. The total distance was 95 meters. Line-of-sight (LOS) between Tx and Rx antenna was maintained throughout this measurement series.

The received power in indoor environments is often calculated from

$$P_R = \mathrm{EIRP} + \mathrm{G_R} + 10\log\left(\frac{\lambda}{4\pi d}\right)^m \quad (1)$$

where P_R is the received power in dBm, EIRP is the Tx antenna Effective Isotropic Radiated Power in dBm, G_R is the gain of the receiver antenna in dB, l is the wavelength of the carrier, and *d* is the distance between Tx and Rx.

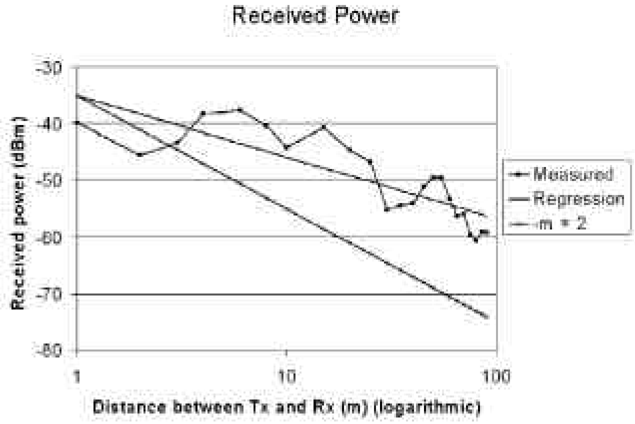

Fig. 2. Received power vs. logarithmic distance between Tx and Rx

The straight line "Regression" in Fig. 2 is a linear regression describing the best fit for the measured values. The line has slope –m, where –m is the factor found in (1). An –m factor of less than 2 indicates a multipath environment. The slope of the regression in Fig. 2 corresponds to –m = 1.1. This is surprisingly low, and points out the vigour of reflected signals. Another straight line, with –m = 2, is also included in Fig. 2 to allow comparison with the theoretic outdoor, line-of-sight conditions where no multipath is present.

Path 2 was perpendicular to Path 1. Smaller gradual power attenuation was expected along the path due to the smaller increase in distance to the transmitter. On the other hand, there were several objects along Path 2 that represented obstacles between the Tx and Rx antenna. Power dips due to shadowing effects behind these obstacles were expected. The results from measurements along Path 2 are illustrated in Fig. 3. The total length of Path 2 was 30 meters.

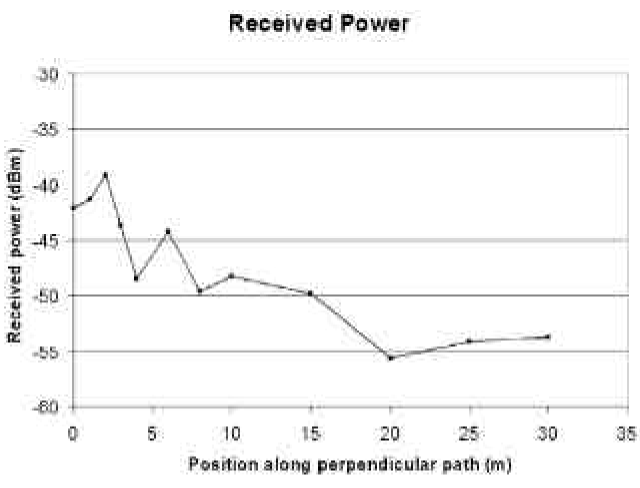

Fig. 3. Received signal power vs. position along perpendicular path (Path 2)

A decaying tendency is observed as expected due to the increasing distance to the Tx antenna. The LOS between transmitter and receiver was obstructed at the following measurement points: 4m, 8m, 10m, 25m, 30m. The first two of these obstacles are clearly visible in the results. Obstacles towards the end of the path are not visible. This indicates that there are multipath components present in this area that are comparable in strength with the line-of-sight component.

Similar results are obtained in other industrial environments like Nuclear Power plants, cable factories etc.

C. *Multipath fading*

In an indoor environment, the received signal is made up of numerous attenuated, reflected, diffracted and transmitted versions of the original signal. Such multipath propagation results in a received signal whose amplitude significantly changes with location. This phenomenon is known as multipath fading. The latter is decomposed into two categories: slow fading (or shadowing) and fast fading. Fast fading consists of the phasor addition of the various multipath signals since each signal presents a specific amplitude and phase. This signal can combine constructively, i.e. a peak, or destructively, i.e. a fade or minimum. Slow fading describes the slow variations in received signal power when the receiver moves behind obstacles.

D. *Chemical pulp factory*

Substantial local variations in power were expected due to the large amount of metal obstacles present.

Multipath measurements were performed with the same physical set-up as the received power measurements described in the previous sections. Only the spectrum analyser settings were changed. The measurements were performed by pushing the Rx trolley with constant speed along a straight line during the sweep time of the spectrum analyser. Various sweep times were used.

Fig. 4 illustrates typical indoor multipath characteristics, with occasional fades imposed on a curve showing gradually decrease of received power as the receiver is moved further away from the transmitter.

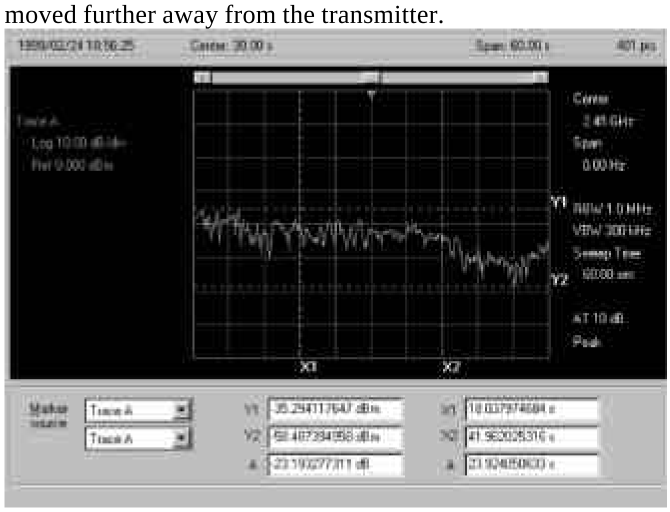

Fig. 4. Received power vs. time (distance) for a 60s sweep from 5 m to 33 m along Path 1 (LOS).

III. Bluetooth in Industry; Possibilities and Limitations

The Bluetooth technology opens up new possibilities for using wireless communication in industrial environments due to its low price and build in security. Wireless communication does however have some inherent advantages and disadvantages, which ABB are considering carefully when utilising wireless technology in industrial environments.

The main advantages of wireless communications in general are;

- No need for communication cables
- Flexible topology
- Mobile applications are possible

The main disadvantages are;

- Sensitive to interferers (share radio frequency with other devices)
- Security (confidentiality, integrity, message tampering, spoofing, privacy)
- Resistance to and detection of service denial (jamming)

In order to benefit from the most obvious advantages, which are mobility and removal of all wires, the power supply issue has to be solved. In some applications power might be supplied locally for other purposes, hence it is possible to power the wireless units as well. A lot of applications however want a complete removal of cables, and power must be obtained by other means, e.g. battery, local generation, solar panels etc. In ABB the alternative power supply issue has been viewed as a main challenge in order to make wireless a success in industry.

Bluetooth has different advantages and disadvantages than wire less in general.

The main advantages of Bluetooth are;

- Low cost, low power
- Security, which is build into Bluetooth

The main disadvantages of Bluetooth are;

- Share bandwidth with many other systems
- Short range, (long delay)
- Sensitive to jammers

Bluetooth links will be available everywhere, and will allow industrial equipment to interoperate with portable computers, palm tops, and mobile telephones. Numerous ABB products should contain Bluetooth modules in the future for seamless connection with office automation equipment. The low cost of Bluetooth does also open the possibilities to introduce wireless in other industrial applications like, sensing, data collection, monitoring etc.

IV. Industrial Requirements to Bluetooth

Bluetooth is originally designed for commu nication between computer equipment, mobile telephones, and peripherals. It can be used as data/voice access points, ad hoc network, and cable replacement purposes. The packets are optimised for voice application, file transfer, and applications like business cards telephone numbers etc. Industrial applications are somewhat different. The messages are often short, but it is important that the information is transferred swiftly and securely. Time stamping of such messages is also widely used. Bluetooth has currently an ARQ scheme (except for voice packets), which make a deterministic data transfer difficult. In the future version of the Bluetooth specification transparent data packets should be made available. This will allow the application to receive packets at scheduled times even if they may contain errors. The application can the decide if the packets should be retransmitted or if other actions should be made.

Industrial equipment is often installed in harsh environments, with extreme temperature, vibration etc. This introduces new requirements on the hardware. The Bluetooth module used in industry should be able to withstand –40 to +80 degrees, and have a robust design.

Power consumption is also a major issue since power is normally not available. A battery solution is not attractive, since the benefit of introducing wireless is soon lost if personnel have to replace batteries regularly.

Summing up the main industrial requirements to Bluetooth;

- Reliability
- Transparent data packets
- Possibility of time stamping
- Power consumption
- Increased temperature range

V. ABB's Experience with Bluetooth

ABB Corporate Research Norway has now a considerable experience in using Bluetooth both the hardware and the software stack. We have implemented/ported the Host protocol stack on to Intel and Motorola processors and microcontroller. The software has run under different operating systems like NT, WIN98, pSOS, VxWorks and no operating system at all. The problems encountered have been relatively minor at least considering that Bluetooth is still in its early stages.

VI. Bluetooth in the new ABB Controller

A. *Bluetooth on AC800M*

ABB is a large supplier of controllers for industrial control and automation systems. The controllers are typically distributed throughout the plant and run production processes, conveyors, machinery etc.

ABB has developed a new generation of controllers. These need communication for system engineering, installation, and maintenance. The communication link must be robust and inexpensive. Infra red communication (IrDA) has been investigated but has shortcomings, since line of sight and hence an open cabinet door is required. A radio solution could overcome such problems and be even more flexible.

ABB Corporate Research Norway has been able to demonstrate the usability of the Bluetooth technology in replacing the serial RS232 cable connecting the PC/NT running the Advant Control Builder application and the AC800M controller. This can give easy access to the controller in the field. Fig 5 shows a picture of the real AC800M controller implementation with Bluetooth.

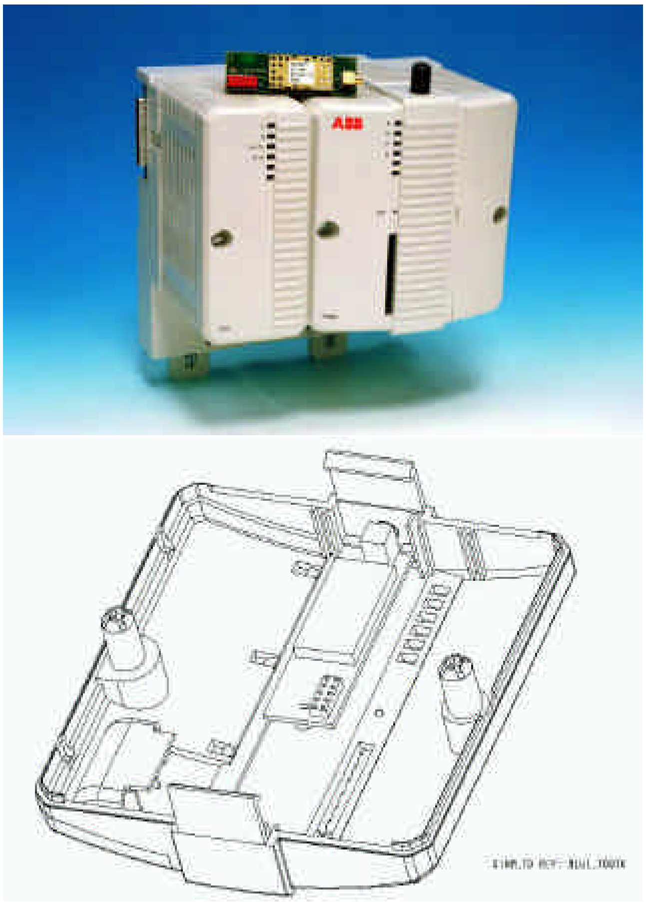
FIG 5; Bluetooth radio integrated in ABB Controler AC800M

The Bluetooth module has been designed into the housing of the new ABB controller. This includes in addition to the transceiver an internal antenna, matching network, and connector for external antenna for outside cabinet mounting. Bluetooth drivers (SW) for the controller processor have been written, and Bluetooth software has been ported from to the real time operating system utilised in the ABB controller. A prototype system has been assembled, thoroughly tested and evaluated. The performance of the communication system has also been verified.

ABB Automation Products (SEAPR) demonstrated as the first industrial Automation Company in the world an industrial application with a Bluetooth link inside at the Interkama fair in October 1999. This allows seamless integration of ABB controllers with office-automation equipment. This first application offers a short-range link providing flexible and reliable data connection for support of installation, commissioning and maintenance tasks.

B. *Windows NT and Bluetooth*

The approach was to enable SattLink to use Bluetooth for the communication. SattLink is a proprietary protocol that uses a RS232 serial channel as the physical communication medium. On the NT platform the selected solution was to implement an intermediate NT kernel driver that handled the Bluetooth protocol. This driver was inserted above the NT serial driver but still in the kernel mode, such that the WIN32 API for serial communication could still be used. This was the least intrusive approach and required no changes to the PC/NT application using SattLink, see fig 6.

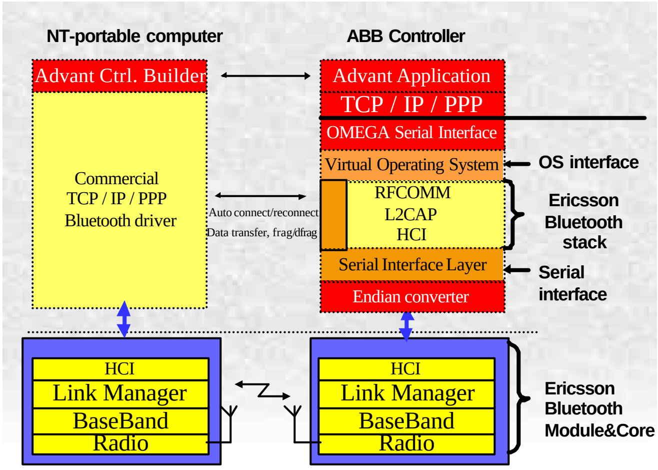

FIG 6; : The Advant protocol stack

The structure of the I/O system on a PC is shown in fig 7 with the Bluetooth device driver present. The Bluetooth device driver does not affect the Win32 API, and is totally transparent to user applications.

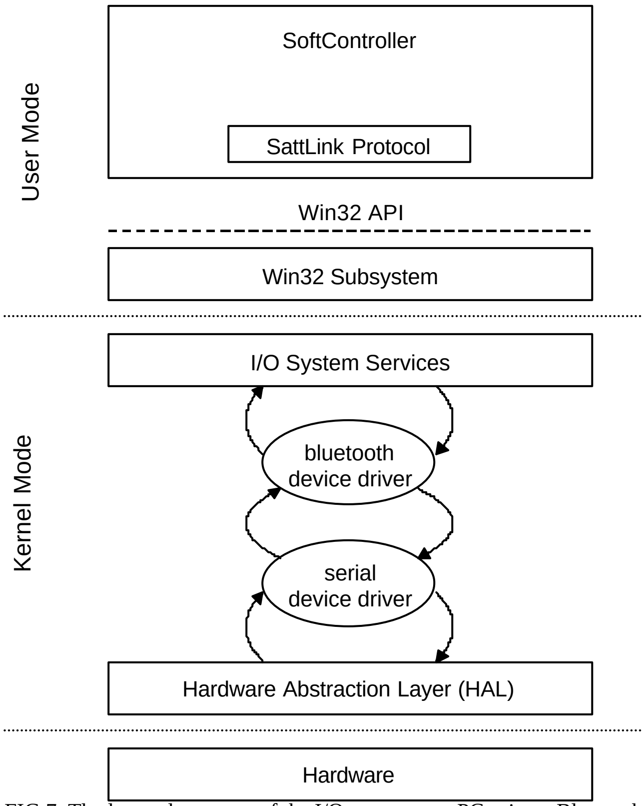

FIG 7, The layered structure of the I/O system on a PC using a Bluetooth device driver

The Bluetooth driver will intercept all I/O requests destined for the serial driver. The only requests of interest are the read and write operations. All other requests are passed along to the serial driver unchanged. The following actions are carried out in the Bluetooth driver:

- The Bluetooth driver performs segmentation and reassembling if necessary.
- The driver handles the specific Bluetooth interface.
- The driver exchanges data with the I/O System Service via local buffers.
- The Bluetooth driver handles requests that are unsuccessful, by either retrying the request and/or returning an error to the user mode application.

The Bluetooth part of the project has required the following SW developments:

- Porting the Bluetooth stack (RFCOMM, L2CAP and HCI driver) to the host platforms.
- Implementing the interface layer between HCI driver and physical interface.
- Implementing the interface layer between L2CAP and adapted protocols (e.g. TCP/IP/PPP or direct serial port emulation).

This project has been one of the very first real Bluetooth applications in the world.

VII. CONCLUSION

The conclusion of numerous field tests executed by ABB is that industrial environments are harsher than office environments. This is due to steel construction creating reflections, obstructing machinery, possible electromagnetic interference from large rotating machinery, large production halls, and though environmental requirements. The field tests have shown that wireless links function well, and the coverage is good. Heavy multipath fading can be seen, and the fading seems to follow a Rayleigh distribution. Multipath propagation is not only an enemy under such conditions, but also a friend

The Bluetooth technology is interesting also in industrial application, especially due to the low cost, and high-speed data transfer. The build in security is also an advantage. Future ABB products will contain Bluetooth in the future.

Industrial applications have different requirement to Bluetooth than office automation. Issues like Reliability, transparent data packets, and power consumption have to be addressed in the new versions of Bluetooth in order to open up even new possibilities in industry.

ABB has considerable experience with Bluetooth, running it under several different operating systems, on different processor platforms etc. The problems encountered have been relatively minor. ABB is proud of the new ABB controller shown at the Interkama fair in October 1999, with a Bluetooth link between the controller and a laptop. This was the first industrial use of Bluetooth in the world.