Bluetooth in service and production applications.

By Kent Lennartsson, KVASER AB
www.kvaser.com

This paper will describe the experience we have gained using radio communication, namely Bluetooth, in a industrial environment. It will describe possible uses, how Bluetooth will work as a solution and the problems you may encounter in such installations.

Background

KVASER AB works primarily with CAN communication. CAN is used as the communication bus in automotive, trucks, boats, machines and medical equipment such as dentist chairs and X-ray machines. As soon as you have an application that must have some kind of real-time control, you can include a CAN-bus. CAN is not intended for a mass flow of data like the Internet or an office computer network because it has a limited bit-rate of 1 Mbit/s (in most cases CAN will be used with 125, 250 or 500 kBit/s). However, even if CAN is not intended for high data rates, it can still be used to control the systems in large network routers and telephone system switches. Due to its relatively low cost and robustness, it can also be used in simple machines like vending and coffee machines.

For all such installations, there will sometimes be a need for a wireless connection. To solve this problem we have developed and tested a CAN-to-CAN bridge utilizing Bluetooth. We have also tested and used a radio link based on 802.11. Almost all work have been made within the EU project, Esprit 27035, with cooperation with University of Leeds.

Kent Lennartsson has been with the company since 1985. He has been working with CAN since 1988, and has been involved with different types of standards to utilize CAN. Today he is much involved with educating people in CAN, and in particular with teaching them how to build advanced CAN systems. Mr. Lennartsson is responsible for hardware design and development at KVASER.

Different types of industrial uses of Bluetooth.

The main use of Bluetooth in industry is to replace sections of the cable where it is complicated and costly to have a cable. There is some work made to have a complete control system based on wireless communication. Such installations was the main target for the mofdi project, but it will need several years of experience and testing before we have reached is goal.

Replacing moving cables.

Bluetooth can be used in situations where you have a moving part in the machine or, even more complicated, if the part is rotating. A cable that moves back and forth will have problems sooner or later. If the part is rotating is it almost impossible to have a computer communication.

When having rotating parts it is possible to have slip rings but they have to be of very high quality. The problem with slip rings is that the high signal frequency for digital signals makes it almost impossible to have noise filters. If the slip rings changes the impedance just a few micro-seconds, that change could be enough to cause a complete data package to be corrupted.

In many cases it is possible to have optical links. The problem with optical solutions is:

- The optics must be aligned.
- The optic path must be free of dirt.
- The optics must be robust enough to withstand vibrations and the environment.

Production line.

When you have a car on the production line it is highly useful to check that the mounted parts are working. Today, this is accomplished by connecting test equipment to some kind of connector in the car. This connection must be disconnected before the car is moved to the next location. Additionally, this set-up requires a cable across the working area. However, if a radio unit is located in the car, it will be possible for every working cell to get in contact with the car automatically all through the production line. When the car is moving between the working cells it will be possible to make tests and download software to the electronic units in the car.

Service and diagnostics.

Imagine you have production equipment with CAN communication and with some IO or control units. If you need to service any part of your equipment, in most cases you will need to see the communication and even exchange some information between the test equipment (PC-computer) and the unit. To do this you will need to connect your test equipment to the CAN communication. First of all you have to find a connection point within a cable length to the location of the unit and second it should be possible to connect without interrupting the communication.

In this case is it very convenient to install one radio unit at a test connection and then have a Bluetooth link between this point and the test equipment. This makes it possible for the service engineer to move freely between every node in the system or close to the controlled equipment. This can be done without limiting the movement of the service equipment because there is no cable connected to the test equipment.

For service, it could also be useful to use the infrastructure of Bluetooth where you can get access to the equipment via the PDA or mobile phone. The main problem here is the need for a firewall and/or the restriction of what you can access, and even more important, how you can control and make changes.

For automotive service and diagnostics it will be very convenient to have this connection installed in the car. It can the automatically be accessed when the car is at the service station and the system can make a first computer based checkup of the car. This will provide some suggestions for the service technician when he come to the car. If the fault can be solved by software updates it can be done directly and the service man will only have to check that there are no more problems. This system will also secure that all cars get the latest software version before they leave the service location.

Temporary installations.

This is the case when you need to add equipment during a short time where the cable and installation cost is a major part. If you have made test or measuring equipment based on radio communication, it can be ready to work as soon as the equipment is located and you turn the power on.

Problematic installations.

A typical problem is a connection to a high voltage installation. This cannot be made with an ordinary cable because that will cause a short. It is even hard to do with optical fibers, because it must be of a type that can survive the high voltage along the fiber. Even if the fiber is isolating you from the high voltage, you still have to consider the potential danger of water and salt on the outside of the fiber. The use of radio will remove this danger of getting power between the two units. There is a minor problem to provide power to the radio unit installed on the power line, because you do not want to turn off the high voltage power too often for battery replacement.

Another problem is explosive areas where you cannot cross with a standard cable. A radio communication with a few mW is normally not a problem.

A radio link can also be used to cross a river or a road. In many cases it is less cost to use a radio than to have a cable across such locations.

Even if Bluetooth is intended for shorter distances it is still possible to use over longer distances with 100 mW output and directional antennas. In this case, radio communication could be of lower cost compared to a long cable. First of all is there the cable cost, and added to that there is an installation cost. After the installation will there be maintenance costs as well, since the cable has to be protected from damage.

Industrial demands for wireless communication (Bluetooth).

The general demand for all industrial applications is the real-time performance. In most data communications, the main goal is to have data sent over the link without any errors. In industrial applications it is necessary to have the information within a certain time. This is even more important than having correct data. Not that you would like to have wrong data, but it is better to get a message with the data in time with the information that it is wrong. If you get some information about the error, it may be possible to recover the necessary information. If you know that you have errors in the data you will use some kind of backup procedure and hope that you will get better information next cycle. The worst that could happen is that retransmission of unessential information will block critical information. For example, it is more important to have access of the brakes than to get the water temperature. Those basic functions can be found in the SCO links in Bluetooth used for voice transfer.

How Bluetooth fits into industrial demands.

Bluetooth runs at 1 Mbit/s
Maximum bit rate in CAN is 1 Mbit/s and in most installations is it less than 500 kBit/s. This is raw data rate and the effective data through-put is in the range 20 to 75% of the basic data rate.

Bluetooth is made to replace cables.
This is the main goal for industrial radio links today. Today you are using a cable that is either causing mechanical or electrical problems or restricting the movement of the operator.

Bluetooth has short messages.
In a control system most messages are very short, with messages like ON/OFF, or signals like speed, pressure and temperature stored in one or few bytes of data. A CAN-message has at maximum of 13 bytes of information.

Bluetooth has fixed time slots.
This will make it possible to guarantee the real-time performance in the communication link. A CAN-message easily fits into such a Bluetooth time slot.

Bluetooth is made for short range.
Most problems in industrial application involve replacing a cable between two moving objects. Such installations are normally less than a meter and can be as short as a few centimeters.

Bluetooth is not made for a global network.
An industrial installation is normally only a point-to-point communication. Even if the installation is more than two units, it is a fixed communication link. In very few installations will it be necessary to have a hand-over from one radio to a second radio. Even if one radio is moving around it is still a fixed link between two radios in a point-to-point link.

Bluetooth has SCO-links with real-time functionality.
Bluetooth has reserved the potential to have three SCO-links for voice transfer. The demands in the voice data are very similar to the industrial control data because both have a time constraint that must be kept.

Problems to be considered for Bluetooth in industrial applications.

The main difference between a normal Bluetooth network and an industrial radio communication is the utilization.

Bluetooth is intended for an office use where:

- In a office network will there be a number of different modules in an installation.
- The nodes in the network will also be changing when you are moving from the office to the car and again when get to your home.
- The user of a Bluetooth network will buy a Bluetooth unit in a store and expect that it will work and provide service as soon as she turns on the power.

The demands in industrial application are:

- In industrial application you will make an installation with a predefined set of units.
- Such installation will never be changed.
- The user will buy a tested setup that is installed with a certain secured performance.

Because Bluetooth is intended and written for office use to be a wireless cable replacement, you may have problems when making a direct use in a industrial application.

We have found the following problems when utilizing Bluetooth in an industrial application:

- ♦ The unnecessary low performance.
- ♦ Power consumption.
- ♦ Lack of information.
- ♦ Lack of control.
- ♦ Temperature range.
- ♦ Multi path spreading.

Low performance

The basic performance in Bluetooth is 1 Mbit/s and time slot of 1.25 milli second. This can easily turn in to a bit rate 20 kBit/s and a delay of more than 35 milliseconds when information is passed trough a Bluetooth profile.

The raw bit rate of 1 Mbit/s is not the problem, because CAN also runs at 1 Mbit/s, or even less than that. Of the 1 Mbit, some is used for synchronization and to cover clock deviation so the true through-put is symmetrical in the range of 172 to 433 kBit/s. If you have an asymmetrical communication it will possible to increase the through-put in one direction to the cost of lower through-put in the other direction. See table 1 for the through-put at different conditions. If there is more than one slave, all slaves have to share this band width.

It can also be noted that with 108 kBit/s it will be possible to have a delay of less than 1.25 milliseconds, that will increase to 6.25 ms if the data through-put is increased to 433 kbit/s. Given that a delay of less than 5 ms in the radio link is acceptable, it is obvious that use of Bluetooth is a technical challenge.

This is the basic performance in Bluetooth given by the technical solution. On top of this, Bluetooth SIG has added a layer of software including baseband, HCI, L2CAP and a Bluetooth application profile. None of those software layers have any time constraints in the Bluetooth specification. This has resulted in a measured delay in the range of 6 to 35 milliseconds in a standard software stack. This measurement is made with a high performance software profile with direct connection to the L2CAP.

If a Bluetooth standard profile like RFCOMM is used it will be even worse. First of all, the through-put decreases from the minimum 172 kBit/s to something in the range 25.7 to 128 kBit/s. Added to this lower bit rate is the increase in delay caused by the RFCOMM software layer.

It should be possible to get real time performance is the SCO-links. Those should have better performance, but have not been tested, because SCO-links are only supported via PCM code and not through UART and USB data package in the Ericsson unit we have used. It seems unnecessary work to convert data packages into audio PCM streams to be packed into data packages over Bluetooth and then converted back to PCM to be converted back to our data packages. The second, and even larger, problem with PCM is the data processing assuming the PCM information to be audio. This function will help to keep a good audio quality, but will not help you when sending no audio information this way. If the SCO links will be available for data transfer in the future they will be a means to transfer real-time control information this way.

Power consumption.

This is one of the problems to consider when moving to higher frequency. Every transistor and connection have a small capacitance and as soon as you turn on the high frequency oscillation will you have to charge and discharge those capacitors. The only solution to this problem is to reduce the capacitor size, that will increase the sensibility to noise, or to turn of the oscillation. Most Bluetooth radios today need about 100 mW with a output power of 1 mW. This power consumption is more or less the same at reception and during transmission, because most power is lost in the internal oscillators. If the output power is increased from 1 to 100 mW, will the unit consume an added 300 mW during transmission. The power consumption is not a big problem in most industrial applications, because a machine consumes normally at least some 100 Watt. There is installations where you have remote placed sensors that consumes where little power where the radio link will be the dominant power consumer. On the other hand will such device normally have a very slow update rate from every second to once every day.

Lack of information.

Bluetooth is made for office where you plug in your equipment and expect it to work. For this reason is it very important that every part of the system is as robust as possible and that as many problem as possible are covered and hidden from the user. The result of this that the Bluetooth software have means to recognize and recover from errors and problems in the communication. The problem is that this knowledge is hidden from the next upper level in the communication stack. The reason for this because no user will be happy to get information like “Your BER is now 23*10E-4". Such information is as understandable as the message “unexpected error 234" from your computer.

In industrial applications are most connections fixed and before it is taken in use are there made a analyze of the performance. It will be very easy to set up a acceptable level of performance that could accepted in that particular installation. Such level that could be used is Signal level "RSSI", the Bit Error Rate "BER", also the distribution of the errors could be of interest. It is also of interest to have this information for every link possible as a statistics with maximum and minimum values. First of all such information can be used to make warnings when you have got changes that may cause a future loss of the link. When you have this information it will be possible to call for a service technician. It can also be used in a investigation to find out sources of disturbance in the environment. With that knowledge will it be possible to remove the source or do changes in the installation that hide you from the disturbance.

Lack of control.

The basis for this problem is the same as for the lack of information. A normal user have no knowledge how Bluetooth is working. The knowledge which changes in the Bluetooth that will improve the performance is even less. It is also very important to have a complete knowledge about the system before you can make such optimization. For a ad hoc installation in a office is it almost impossible to know the system is working for one minute to the next.

In a industrial application where you have a temperature sensor sending only this data every seconds for the next 10 years via Bluetooth it is much easier. In such installation it will be possible to select the best error protection based on some measurements on the communication before start of use. The best error protection and or correction may not be the one included in the Bluetooth standard. It could also be that when you get error it should be retransmitted only once then dropped. In some cases it is better to send it twice every time because the disturbance is very rare but when you get errors it will not be recovered by the FEC built into Bluetooth. The best configuration may also change over the 10 years is it in use.

Temperature range.

Until this spring was the possible temperature range for Bluetooth 0-50 degree Celsius. Some claimed it could be possible to increase this range to -20 to 70 Celsius. Fortunately will a important application for Bluetooth be a connection between the telephone and the handsfree kit in the car. For such application in a car will it be necessary to have unit working at a wider temperature range. At the Bluetooth conference in Monte Carlo a number of silicon producers claim they could work up to 85 Celsius and some claimed that even 100 Celsius is possible.

We will never see Bluetooth in the full automotive temperature range -40 to 125 degree Celsius, at least not in the near future and it will not be a mass produced low cost solution.

Multi path spreading.

The main problem for radio units in installations in areas with metallic parts is multi path spreading. Due to cost, is the modulation in Bluetooth not optimized to handle signal spreading. This is still a minor problem in cable replacement with insight communication. If there is no direct visual link between the two antennas this could be a problem. It could also be a problem at long distance links.

How to select the antenna and radio power in industrial applications.

It is important to keep the power level low in a industrial application.

To keep the RF information within a limited area.
To prevent your communication to disturb other radio links.
By directional antennas secure that the RF-power is kept within a restricted area.
A directional antenna will also make it possible to increase the distance without increasing the power. This is very important when you have a battery powered Bluetooth unit.
Directional antenna will reduce the problem with spreading because it will decrease the spreading and increase the main lobe power.

During the mofdi work have we found it very important to keep track of the signal level as well as error intensity. With such information will it be possible to secure that you have a certain communication quality. If you have to low receiving power or if you get to many errors in the communication it will indicate that some kind of service or adjustment is necessary in the communication link.

How to improve Bluetooth in industrial applications.

The need here can be founds from the section above describing problems with Bluetooth in industrial applications.

Temperature range problem.
For must indoor industrial applications is the today temperature range 0- 50 degree Celsius enough. We could expect to get parts within the next year that will work with the -30 to +85 degree range and that should cover 90% of the industrial installations. There is a number of installations within a machine that can get cooler or warmer. Those problems have to be solved by having the radio mounted in a box with a heater or a cooling equipment.

The unnecessary low performance.

The communication can be divided into following layers.

Application at first unit
Profile e.g. RFCOMM, OBEX etc.
L2CAP
Host HCI interface.
Base band HCI interface.
Base band handling.

RF-link

Base band handling.
Base band HCI interface.
Host HCI interface.
L2CAP
Profile e.g. RFCOMM, OBEX etc.
Application at second unit.

The main problem for realtime is the delay caused when the information is passed trough those layers of hardware and software.

RF-link
This part is the main part of Bluetooth and any modification here will in most cases make it into something that is not Bluetooth. The only possible change is in the power and clock control. The Bluetooth standard describes a number of fixed power levels that should change ad hoc according to some standardished rules. It could be possible to have a more advanced power measurement as well as power control. This is possible to do in industrial application because the installer will have knowledge and he will have a fixed installation where he can optimize the function. It is also possible to improve the communication if you have better clocks and clock synchronization than specified in the Bluetooth standard. Both those modifications should be possible to use without violating the standard.

Base band handling.
The main problem today is that this application is running asynchronous to HCI, host and application. Even worse is that the SCO-channels that guarantied realtime performance only can be used trough the analog PCM channel. Today is it impossible to utilize the SCO links trough the HCI interface. All ACL links area placed in a queue processed unsynchronized with the radio slots, PCM signals and the communication trough the HCI link. A delay of almost 4 milliseconds have been found from the complete transfere of a HCI frame until it is placed in the air.
If this part is written with the goal of accessing the SCO links with full performance it should solve most realtime problems. Such a implementation should solve 80% of the problems. If this software also includes some kind of synchronization to the applications it will really improve the complete solution.

Base band HCI interface.
The problem here is the low performance in the hardware. The UART will not work very good beyond 400 kBit/s and the USB connection have to small endpoints to provide more than 240 Kbit/s. To really get the most of the communication is it necessary to synchronize the HCI slots with the RF-slots. This is little tricky with the USB having a slot every 1.00 millisecond and Bluetooth having one every 1.25 millisecond.
The work here will be to utilize a USB link with higher performance, possible dedicated for this task.

Host HCI interface.
This improvement will more or less be the same as of the base band HCI interface, but for the other side of the link.

L2CAP
This part of the Bluetooth stack is causing a lot of problems as it is specified today. This part is not designed for realtime applications so there is a lot of functions missing. The work here will be to design a realtime L2CAP. It will need some added information during configuration, but it should be possible to have a default setting identical to a standard Bluetooth unit.

Profile e.g. RFCOMM, OBEX etc.

To get real realtime performance it will be necessary to make new profiles. It will be possible to write a RFCOMM unit where you have some hidden control that will fit into the Bluetooth standard and still have some improved realtime function.

Application.
When all layers are improved to secure that the delay trough all layers is as small as possible is it time to do something about the task. The most important task here is to synchronize the application to the Bluetooth transfer. The goal here is to prepare the information and when passed to RFCOMM it will pass true all layers with a minimum delay and reach the base band unit just in time to fit into the next Bluetooth time slot. The same will be true on the other side and when the application is started and read the information is have just arrived with a delay of 2.756 millisecond.

Lack of information and control.
This is also a problem related to the Bluetooth specification, because this is information that is not described as something provided by Bluetooth. This is something that have to added to the base band software. The information is already there and it is to some extent already used by the base band application. The only parts that have to be added is some software that makes this information available for external software. The same is true for the means to control the base band function.

Practical experience from industrial applications.

We have found that for simple tasks over short distance is there no problems to use a Bluetooth link. The possible realtime performance is limited and a delay of 35 millisecond must be accepted. It is also hard to get more than 50 kBit/s over such link. To secure a better performance we will need better optimized software in the base band unit.

Our main concern was the spreading of the signal power, because of the great amount of metallic parts in a industrial installation. We could see that a transmitted signal in one corner of a industrial location could be detected at almost any location within the room. The problem is not to get a signal level but to have the energy unspread in the time domain. We could also see that GFSK is not the most optimal technique when it comes to robustness against spreading. After some test we found that this problems is not as large as expected when it comes to the real problems.

Spreading is a minor problems at short distance or when there is a direct link between the two antennas. This is because the main signal will have a much higher signal strength compared to the reflected signal.

We have also tested a number of antennas and found that something that have the very same specification and looked almost the same could be very different when it comes to a real application. We tested four omni directional antennas and found that the communication distance was 10,15, 30 and 50 meter for the very same radio par with 0dBm. If we did use the best omni directional antenna together with a special antenna to be placed on the wall covering a industrial area in front of the wall we could cover a radius of 120 meter. This should be compared with the omni directional with the 10 meter range that hardly should reach 100 meter even with 20dBm output power.

The conclusion is that the selection of antenna, cable and location is essential for having a reliable communication link. A bad electron-magnetic link is hard to compensate with more power. A god link will also make the system more insensible to disturbance and spreading.

One key factor in the future development is the antenna technology. When it comes to the mobile phones is there a lot of work done in the development of antennas. We will in the near future see units with at least two antennas, one for reception and one for transmission. If such device is optimized and matched against the electronics it will be possible to remove a great numbers of passive components and switches.

The problem left for test is a long time test to secure that the communication link will have a certain quality over a longer period of time. This is very interesting for out door application where we have to check the communication over one year period to secure the quality in any weather condition.