Architecture proposal

Report

ATJ-kehitysohjelma

”Ajoneuvon / työkoneen langattomat lähiverkot (ALMA)”

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Abbreviations

AES	advanced encryption standard
ASK	amplitude shift keying
CAN	controller area network
CSS	chirp spread spectrum
CVIS	co-operative vehicle infrastructure systems
DSRC	dedicated short range communications
ETSI	European Telecommunications Standards Institute
FSK	frequency shift keying
ISM	industrial, scientific, medical
MCU	microcontroller unit
MRC	medium range communication
PSK	phase shift keying
RFID	radio frequency identification
RX	receiver
SPI	serial peripheral interface
SRC	short range communication
TX	transmitter
UWB	ultra-wide band
VSRC	very short range communication
WAVE	wireless access in vehicular environments
WPAN	wireless personal area network

1 Introduction

This document proposes wireless technologies to three different purposes in working machines such as harvesters, trucks, excavators etc. The main application focus is for safety critical solutions. These three purposes are defined with non-standard abbreviations as follows: First, a very short range communication (VSRC) method is for power and data link in a ball-end handle controller for distance of few centimetres. Second, a short range communication (SRC) method for a wireless control bus within machine’s physical dimensions, up to 30 m. This could realize wireless harvester head control between a cabin and a harvester head. Third method describes communication which is referred as medium range communication (MRC) between two machines. The range requirements are up to few hundred meters and possibly up to few kilometres. Grounds for technology selection are explained and an architecture description is given for all three cases.

2 Technology selection

2.1 VSRC

VSRC is used for wireless communication having operation range of few centimetres. VSRC replaces easily braking cables and enables communication over rotating motion. The application is ball-end handle controller. Inductively coupled power transmission and data link are selected for VSRC. It is cheap, frequency band is license free and it has an excellent immunity to environmental noise and electrical interference.

2.2 SRC

Requirements for wireless SRC are derived from a typical control bus, CAN (Controller Area Network). Reliability and small delays are the most important requirements along with sufficient guaranteed data throughput. A range of few tens of meters must be reached. The control bus cable which is prone to brake will be replaced with a wireless communication. The solution is also suitable in an environment where a wired bus is challenging to be implemented. Standard control bus interface is preserved for easy connection of existing devices.

Most promising standard solutions for short range communication are based on IEEE standard 802.15.4a. Both CSS (Chirp Spread Spectrum) and UWB (Ultra-Wide Band) offer good interference and disturbance tolerance. Both have ultra low power consumption. Their mandatory data rates are comparable to a CAN bus, 1 Mbps and 850 kbps respectively. However higher rates are possible. CSS chips offer non-standard data rate of 2 Mbps and decaWave UWB supports optional data rate of the standard up to 6.8 Mbps. If necessary, more emphasis can be put on the forward error correction of the wireless interfaces i.e. to transmit redundant data for better error correction without retransmissions. 128-bit symmetric key cryptographic security is utilized. Data confidentiality, data authenticity and replay protection are provided by the MAC sublayer security services.

Availability of the radio chips will be adequate, but the number of manufacturers is quite low at the moment. Two suppliers for CSS can be found, Nanotron and STMicroelectronics. For

UWB the first manufacturer is decaWave. Micro Strain should start producing these chips, too. decaWave’s ScenSor prototype chips will be available next year.

The idea is to use two radio interfaces, CSS and UWB. Because radio channel is more vulnerable to outside interference than wire, redundant physical layers gives better chances for uninterrupted data flow. Using two substantially divergent radio bands improves the reliability even more. Failure in one radio or frequency band doesn’t compromise radio transmissions altogether. CSS uses 2.4 GHz band. Two sets of three non-overlapping 22 MHz channels are used or one 80 MHz channel. Nanotron uses the wider channel when higher (1 Mbps or 2 Mbps) data rate is used. decaWave UWB uses seven channels 500 MHz each. Common available unlicensed frequencies for UWB in EU, USA and Japan are from 3.4 to 4.8 GHz and 7.25 to 8.5 GHz.

2.3 MRC

Standard IEEE 802.11p was selected to be used in MRC, see document "Risk Analysis". It supports vehicle to vehicle architecture and it is easy to connect to the information systems of working machines. Standard 802.11p is predicted to be published in July 2010 [1]. 5.9 GHz band is utilized exclusively for vehicle to vehicle and vehicle to infrastructure communications.

A test platform for 802.11p may be available in February 2010. This test platform "LinkBird-Mx" is manufactured by NEC. LinkBird-Mx is an evaluation kit for car to car communication. It is offered to partners of the Car-to-Car Communication Consortium and used by various European research projects, e.g. Co-operative Vehicle Infrastructure Systems (CVIS). Another hardware for testing the 801.11p is available from Kapsch. Their eWave module is compliant with IEEE 801.11p and WAVE (Wireless Access in Vehicular Environments) for Dedicated Short Range Communications (DSRC).

3 Architecture proposal

VSRC is used as communication channel in the ball-end handle inside the working machine cabin. SRC replaces the wired control bus between cabin and the harvester head. MRC is used between machines working in the forest and between machines and infrastructure. Illustration of these wireless connections can be seen in figure 1.

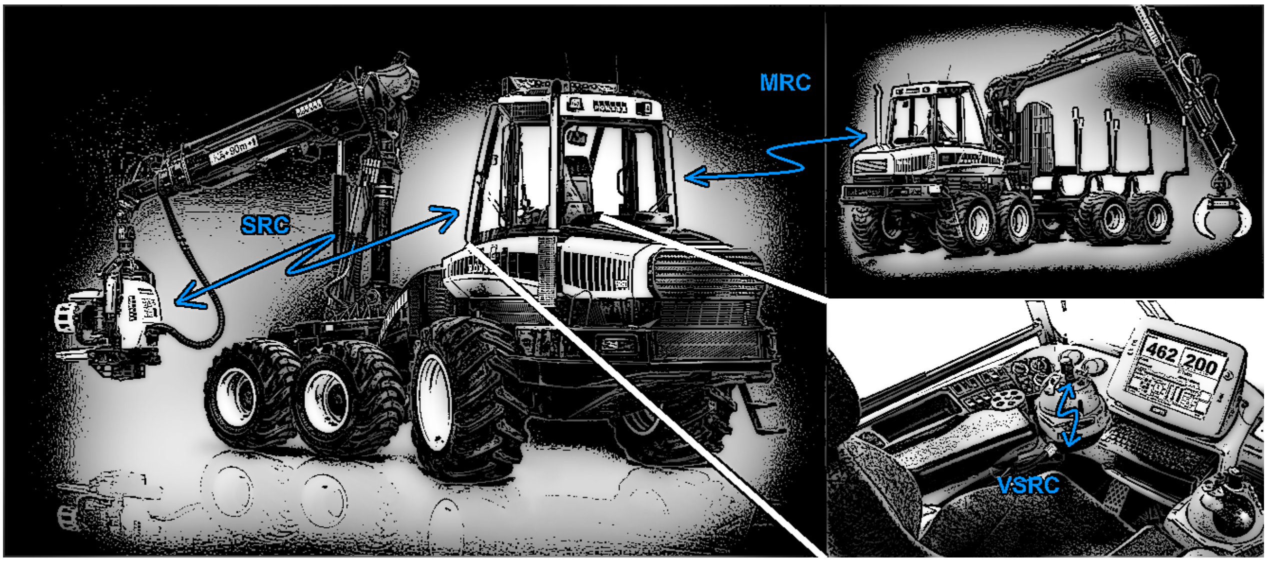

Figure 1 Wireless technology to be implemented in a harvester.

These three communication solutions use separate frequency bands, which will not interfere with each other. Interface to the VSRC, SRC and MRC links will be implemented with a standard vehicle control bus like CAN. In the next chapters technologies and their architecture proposals are described in detail.

3.1 VSRC

Figure 2 presents a schematic of inductively coupled power transmission and data link. Data is modulated over power transmission. Inductive data link implementation can be divided in three main functional blocks. These blocks are: 1) signal encoder and a modulator in moving part of ball-end handle, 2) inductive link and the demodulator and 3) the signal decoder in the body of the ball-end handle. Power is transferred by a coil in the body tuned into resonance to the coil in the moving part which is tuned into resonance, too.

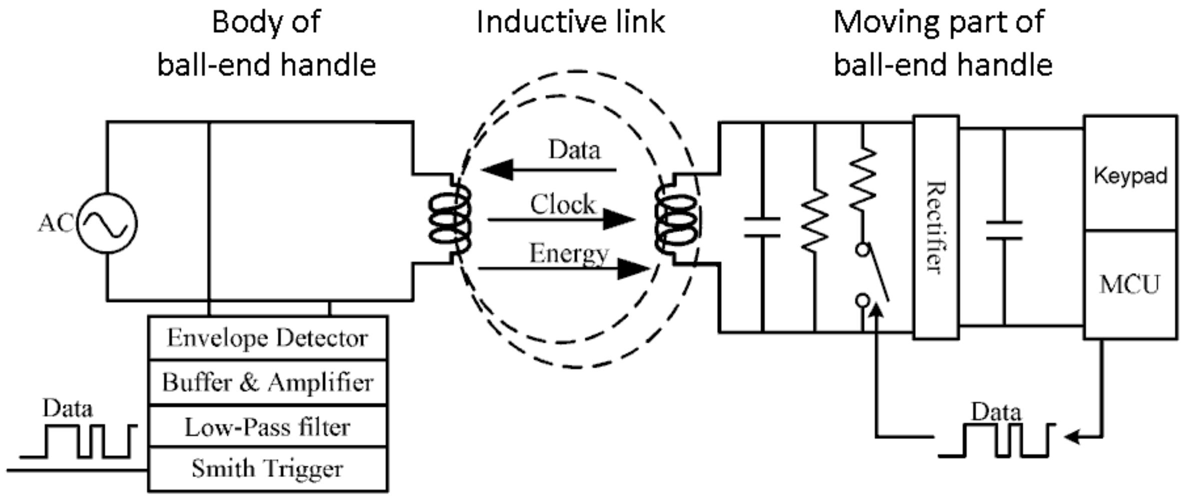

Figure 2 Inductively coupled data and power link.

Inductively coupled systems typically use digital modulation like ASK (amplitude shift keying) FSK (frequency shift keying) and PSK (phase shift keying). Digital modulation is presented in Figure 3. In Figure 4 modulation products using load modulation with a sub-carrier are shown.

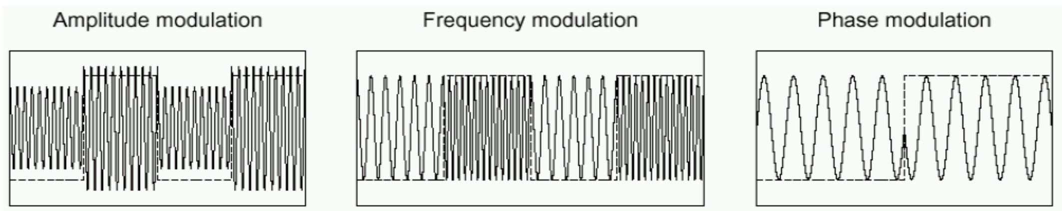

Figure 3 Modulations.

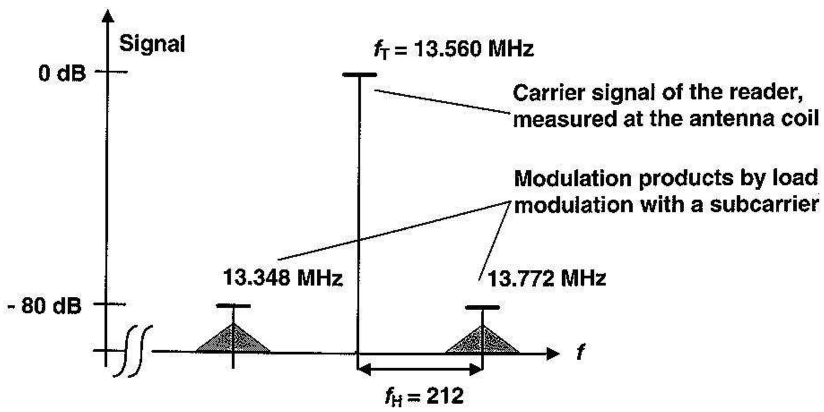

Figure 4 Modulation products using load modulation with a subcarrier.

Bits (one and zero) can be represented in various line codes. Inductively coupled systems typically use some of the next methods: NRZ, Manchester, Unipolar RZ, DBP (differential bi-phase), Miller differential coding and PP coding (Figure 5).

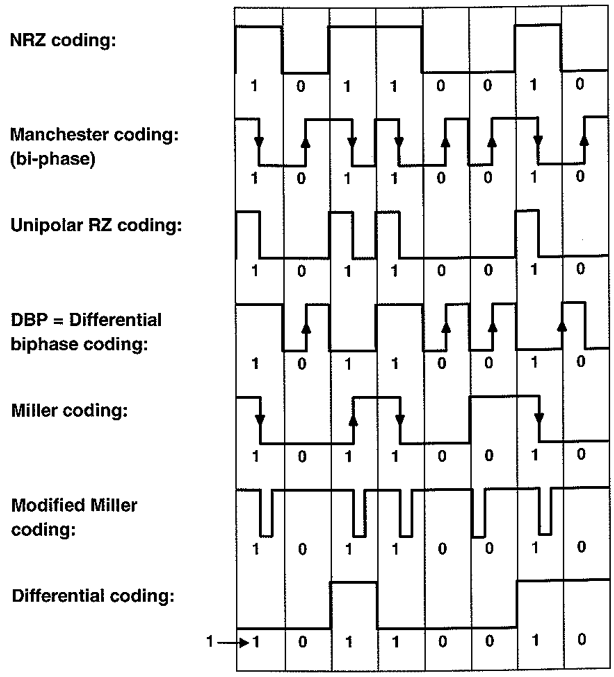

Figure 5 Signal coding by frequently changing line codes in inductively coupled systems.

Modern authentication protocols can be used e.g. advanced encryption standard (AES). Operation range for inductively coupled systems is quite short. Hence it isn't easy to access the system from outside and generate faulty operations. Inductive power link works in ISM (Industrial, Scientific, Medical) radio frequency ranges. These frequencies can be freely used for ISM applications. ISM frequencies are defined worldwide. The most used frequency ranges for RFID (radio frequency identification) and IPT (inductive power transfer) systems are 0-135 kHz, 6.78 MHz, 13.56 MHz, 27.125 MHz and 40.68 MHz. The maximum magnetic field strength is specified in document EN 300 330-1 by ETSI (European Telecommunications Standards Institute). H-field strength limits are shown in figure 6.

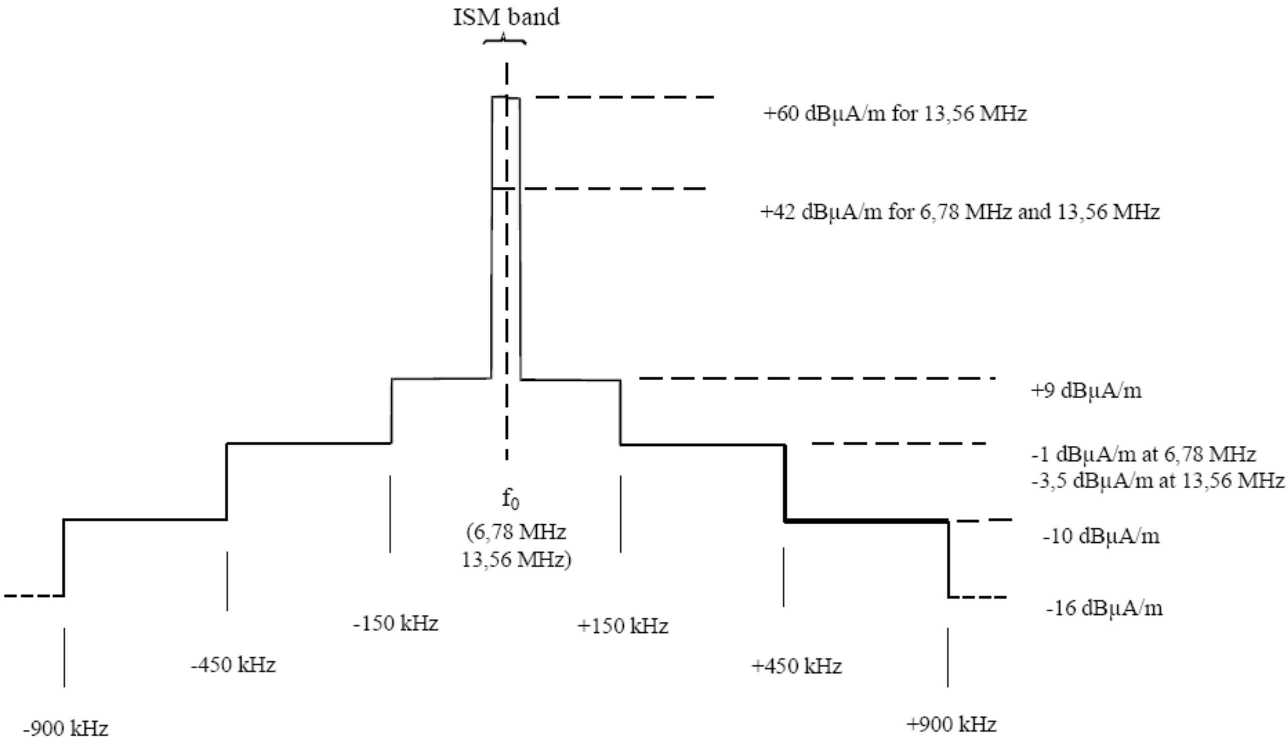

Figure 6 H-field strength spectrum mask limit at 10m.

3.2 SRC

Short range communication radio interface described here is planned to replace the wired control bus connection between cabin and harvester head. In figure 7 is shown a general diagram of the control system. Radio transmission redundancy is achieved by using two different physical layers. More reliable communications can be realized by transmitting the same data over CSS and UWB radios. Low-rate WPAN IEEE standard 802.15.4a based radios are used.

The two control buses in the cabin and in the harvester head are separated from each other. Gateways are used to forward data from one node to another in different bus. Gateways should acknowledge messages received from a node straight away. If acknowledgements from the control bus were to be transmitted over radio interfaces, the roundtrip delay could be too high. In such a case the reply from the destination node could still be on its way when the frame will already be re-sent.

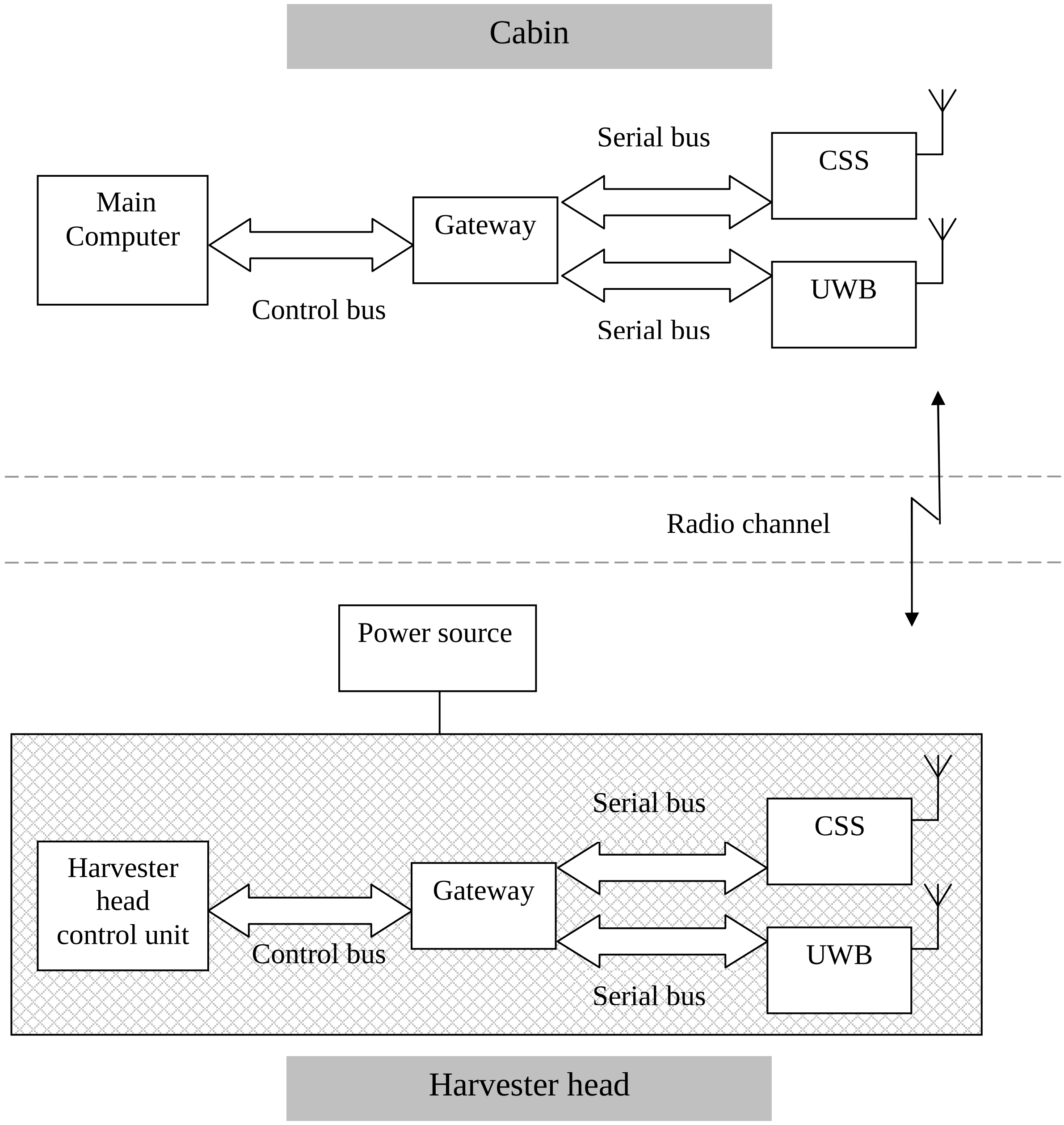

Figure 7 Wired control bus transmission is passed through radio channel.

The antennas could be placed on opposite sides of the cabin. This way interference could be controlled better and line of sight could be maintained with a rotating boom. One possibility could be to use two receiving antennas for either of the radios at the cabin end, so that at least the other radio would always have a line of sight transmission path. Redundancy implementation of the radios is quite straightforward. There is a gateway which receives control signals through control bus and sends them over the serial data bus interface e.g. SPI (Serial Peripheral Interface) to both radio microcontroller units (MCUs). The radios operate independently. Whichever packet from the two radios arrives first and unchanged is forwarded by gateway to the control unit of the harvester head. Duplicate packets will be discarded. Same applies to transmissions to the other direction.

The gateway could be implemented as in figure 8. ARCNET interface is chosen in this example. SMSC's COM2002x series controller is used with Intel's 8051 MCU to interface to the ARCNET bus. The ARCNET controller includes network protocol handling and buffering. MCU will then connect to radios through SPI.

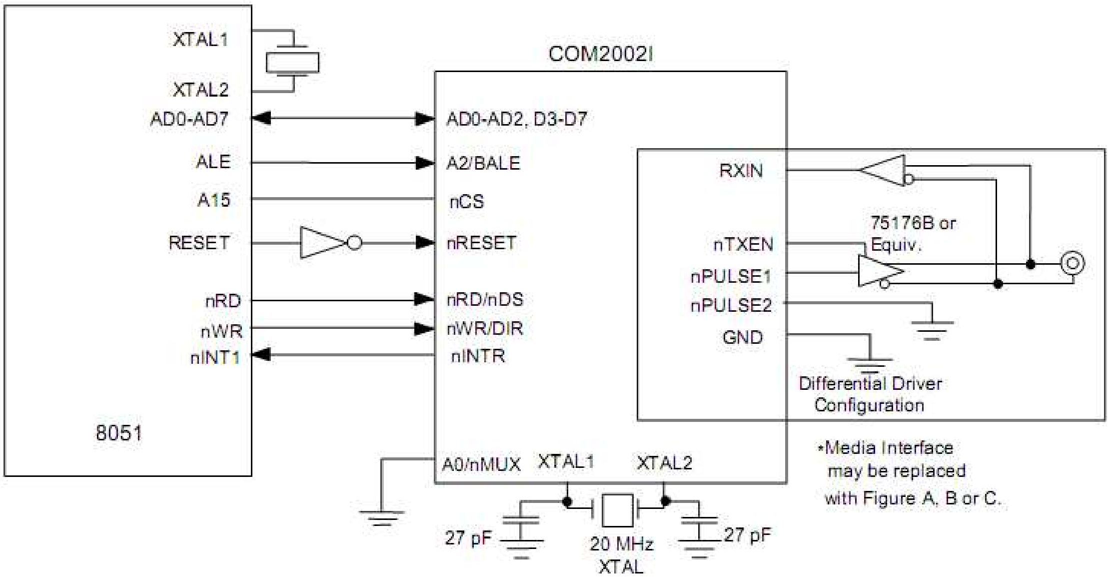

Figure 8 An example of ARCNET interface with ARCNET controller by SMSC.

3.2.1 Assessment of delays

By replacing part of the wires with wireless system inevitably increases delays. The additional components in the system receive, handle and send data increasing processing time. For the radios delay can be assessed by calculating minimum delay one frame takes to transmit. As an example maximum frame duration with maximum sized (128 octets) data packet with 1 Mbps CSS modulation is calculated. The formula for calculation of *phyMaxFrameDuration* can be found in IEEE standard 802.15.4a documentation [2 p. 47]. All the necessary values for the variables can be found from there also.

$$phyMaxFrameDuration_{1M} =$$
$$phySHRDuration_{1M} + \left[1.5 + \tfrac{3}{4} \times ceiling\left(\tfrac{4}{3} \times aMaxPHYPacketSize\right)\right] \times phySymbolsPerOctet_{1M}$$

The formula gives the frame duration in symbols. By multiplying it with the symbol time results in about 1.1 ms. There is a linear dependency between frame duration and payload length. The maximum payload length in packets depends on the length of address and security fields which together take from 4 to 34 octets.

Interframe spacing, in other words required time before new frame can be transmitted after a current one, is 40 symbols (240 μs). For short frames up to 18 octets, the interframe spacing is 12 symbols (72 μs). Turnaround time $t_{turnaround}$ from TX to RX or RX to TX is 12 symbols (72 μs). MCU delays are assumed to be low and those are not estimated here. Delay t_{cycle} depends on the frame size and possible acknowledgement frames, and it describes one full TX / RX cycle until new TX is possible. If more than one frame is needed to carry data interframe space of 240 μs is then added after each frame or 72 μs for short frames. One full transmit and receive cycle with maximum packet size and minimal turnaround times, the t_{cycle}, is less than 2.4 ms. With acknowledgements that is only slightly higher. *macAckWaitDuration* is approximately 0,3 ms so one transmit and receive cycle with acknowledgements is about 2.8 ms (1.1 + 0.3 + 1.1 +.0.3)ms. Delays over the radio interfaces are visualized in figure 9.

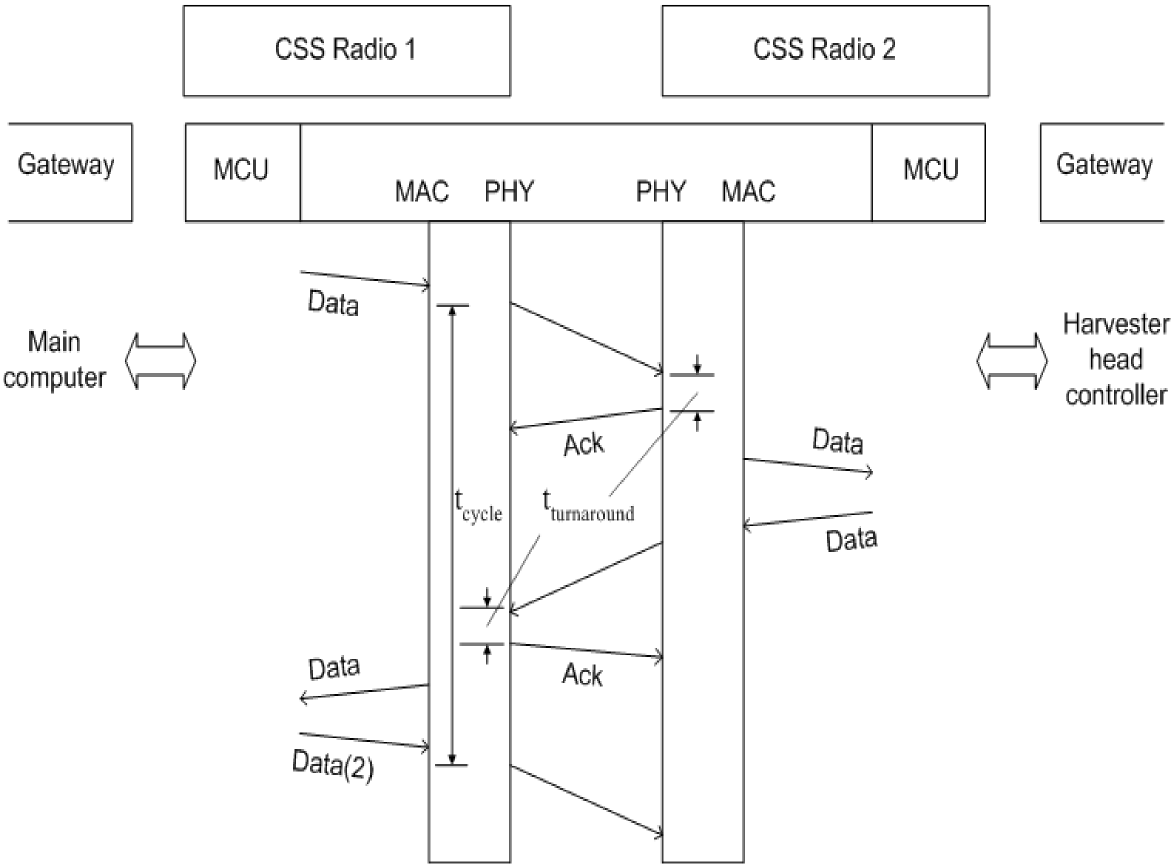

Figure 9 Delays over radio interfaces.

If radio connection between cabin and harvester head for some reason is non-responsive for a certain period of time the harvester head shall be put in a safe mode.

3.2.2 Human response to delays

Delay in the control system can induce a decrease in user performance and pose a safety threat. A more thorough literature study of the subject is done by Kajaani Unit of Department of Information Processing Science, University of Oulu, called “Human Reaction Times as a Response to Delays in Control Systems - Notes in vehicular context” [3].

In flying 100 ms is seen as a limit for a responsiveness of the plane which if exceeded will affect negatively on the performance of the pilot. In virtual environments delay around 70 ms start to show an effect but delay of 25 ms does not have a measurable effect. However people are reported to detect latencies as low as 10 to 20 ms. As a general rule the maximum delay in different kind of systems related to sight, hearing and touch senses in the vehicular control is in the range of 50 to 60 ms. In most cases this delay may be noticed but has no great impact on the performance and humans can adapt to it. [3]

3.3 MRC

MRC is used for communication between machines, e.g. from forest harvesting to forwarders. Maximum operation range of this technology is 300 - 1000 meters. Standard 802.11p is selected for the architecture of MRC. It defines PHY and MAC layers of MRC system. Interface to MAC layer is Ethernet 10/100 BASE-T or corresponding. Block diagram of MRC system is shown in Figure 10.

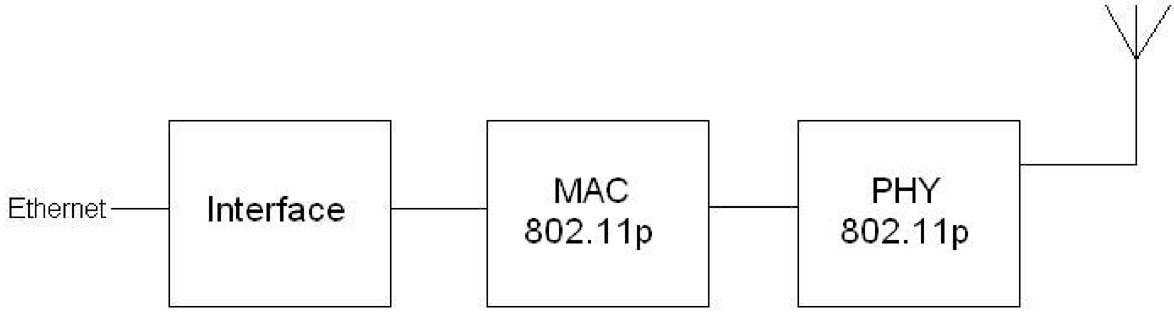

Figure 10 Simple block diagram of medium range communication.

4 Resistance to interference from other devices

Selected technologies must operate reliably close to other RF devices. One source of interference is machine driver's own electrical equipment. The interference sources can be e.g. cellular phone, wireless hands free headset, wireless interface of PDA etc. H. Viittala is author of document "Analyzing Radio Technologies in terms of Disturbances" which analyzes radio technologies in terms of their mutual interference in general.

VSRC

Inductive coupled data link operates in the 13.56 MHz frequency. It is outside of normal RF equipment's frequency band. Some of RF ID devices may be using the same frequency, but their power is so low that they do not interfere. Magnetic field strength is attenuated in the cube of the distance so jammer must be very close to cause interference. Electro-mechanical equipment of machine is a greater source of interference than other RF devices. Also strong external magnetic field generating systems nearby increase the risk of inductive link failure. Such a high magnetic fields can be created by big high-voltage power transmission lines and large transformer stations.

SRC

CSS technology of standard 802.15.4a operates in the 2.45 GHz frequency and bandwidth is 80 MHz which is used for higher data transmission rate (1 Mbps). WLAN and Bluetooth operate in the same ISM band. In addition, there are several non-standard RF devices that operate in the same ISM band. C/I (Carrier-to-Interference ratio) of Nanotron CSS transceiver is about -3 dB and maximum transmitter power is up to 100mW.

WLAN has maximum transmitter power of 100 mW. When Nanotron and WLAN operate in overlapping channels at the same time, data loss is possible.

Standard 802.15.4a UWB technology operates in 3 - 10 GHz band. UWB channels are shown in figure 11. Decawave UWB chip is used in the lowest 7 channels. Channels 1-4 DAA (Detect and Avoidance) techniques are required or equipment must operate with LDC (Low Duty Cycle). Channels 5-7 do not have the same requirement so these are best channels for data transmission. General portable devices do not operate in these frequencies currently. ECMA-368 (WiMedia UWB PHY) is the definition of overlapping channels with 802.15.4a UWB PHY, which caused small interference risk. WiMedia UWB devices are not used widely today. However some of fixed point to point radio links are operating in the same frequency band [4, 5].

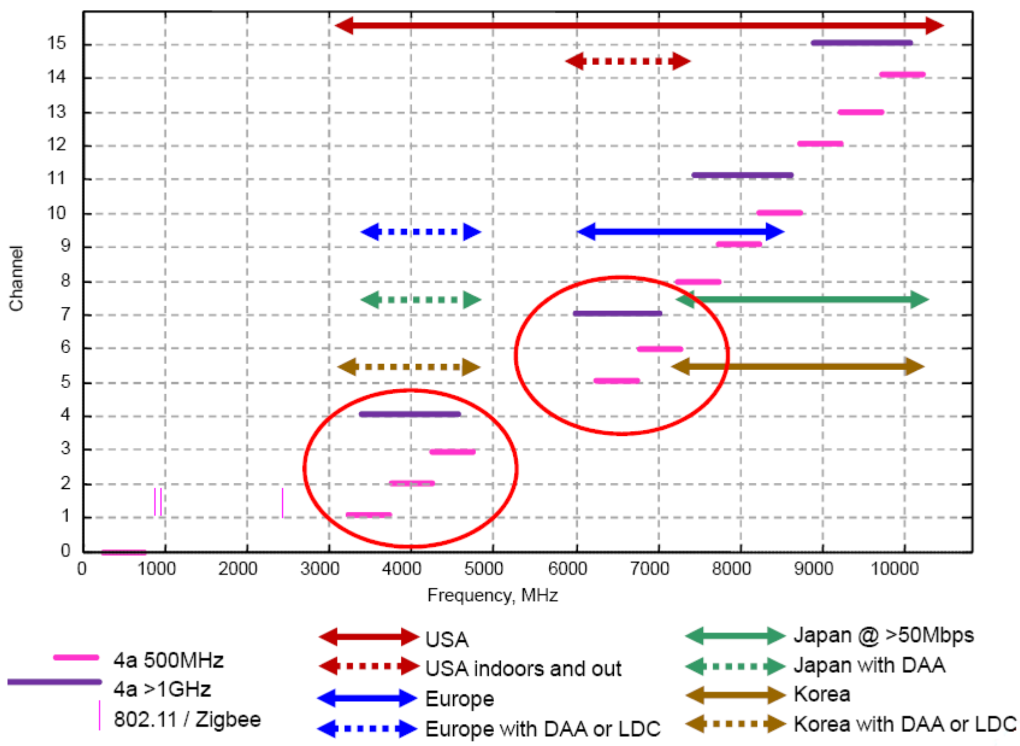

Figure 11 802.15.4a UWB channels [4]

MRC

Interference tolerance of 802.11p is discussed in the document "Risk Analysis - IEEE 802.11p." 802.11p is operating in the licensed DSRC band, so there should not be such interference as in the ISM band.

Conclusions

VSRC

Inductive power link has been implemented in the ALMA project in the spring of 2009. Next step is to implement inductive data link and to develop interface to a CAN-bus. After this, wireless power and data transmission will be piloted in a ball-end handle.

SRC

Two radio interfaces were chosen for SRC, CSS and UWB of the standard IEEE 802.15.4a. By using two radios at the same time the risks of occasional interference, intentional disturbance as well as communication break caused by physical failure can be substantially lowered. CSS is a robust and sensitive radio that can operate in harsh environments. 2.4 GHz frequency band is another challenge. Further testing for CSS interoperability could be done. Some cognitive features and filtering of other interfering signals could be implemented if the situation requires. UWB chips are not yet available to all public.

The delays over radio interfaces seem to stay in an acceptable level. One transmit and receive cycle with full packet size is about 2.8 ms in CSS PHY. 1 Mbps data rate and acknowledgements are presumed to be in use. Payload length further specifies duration of the cycle.

MRC

The most suitable standard based solution for MRC is 802.11p. The standard is still yet to be published but “pre p” and WAVE for DSRC compliant platforms are available. Hardware, which will be used for evaluated MRC technology, will be selected and purchased for piloting.

References

[1] IEEE 802.11 working group project timelines, http://www.ieee802.org/11/Reports/802.11_Timelines.htm

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