Wireless Control Communication for Mechatronic Systems

Květoslav Belda[1], Václav Rychnovský[2]

[1] Department of Adaptive Systems
Institute of Information Theory and Automation
Pod Vodárenskou věží 4, 182 08 Prague 8, Czech Republic
[2] Department of Control Engineering
Faculty of Electrical Engineering, Czech Technical University in Prague
Karlovo nám. 13, 121 35 Prague 2, Czech Republic

I. Introduction to mechatronics and communication issues

Industrial control systems are frequently required to be implemented in heterogenous applications containing lots of components or units being moreover variously distributed and having different static and dynamic properties. In almost all cases, the applications consist of mechanical elements forming machine bodies (mechanisms), electromechanical elements powering or monitoring the mechanisms (actuators - drive units, contact sensors) and purely electrical elements monitoring (other sensors and indicators usually contactless) or controlling (controllers, power electronics) the machine itself. Altogether, it represents connection of mechanics and electronics, in single word - 'Mechatronics' (Fig. 1, [1]), which comprises the synergistic combination of mechanical engineering ('mecha' for mechanisms, i.e., machines that 'move'), electronic engineering ('tronics' for electronics), and software engineering. The purpose of this interdisciplinary engineering field is to study mechatronic systems from an engineering perspective to support their control, in the broad sense of the word, their use.

The systems or their components, to be controlled and monitored, need number of communication channels. The key problem is how to establish and maintain these channels especially in heterogenous decentralized systems. Application of conventional wire connection limits a system movability and furthermore decreases a modularity and connectivity with other systems in the surroundings.

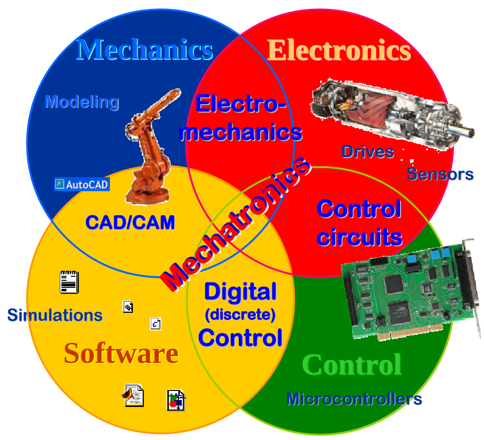

Figure 1: Fields of Mechatronics

Investigation and presentation of the different way of the communication is the subject of this paper. Its contents is organized as follows. At the beginning, there is a brief outline of the possible ways of the data transfer and acquisition. Next, the third section introduces ZigBee communication protocol for full bidirectional wireless data transfer as one of advanced communication protocols for the automation. In the fourth section, the application example of the wireless communication and optical data acquisition is presented. The conclusion section concentrates the main features and possibilities of the presented wireless communication at the application to the closed-loop (feedback) control of mechatronic systems.

II. Possible ways of information or data transfer and acquisition

The communication providing the data transfer for whatever control usually proceeds in the one direction from a control unit to a controlled system component and in the second direction from sensors to the control unit. A selection of the appropriate way of the transfer depends on the required data rate of the controlled system. Ways of the transfer and acquisition in the mechatronics point of view may be summed up as follows:

▷ Information or data transfer communication means:

- wire channels (metallic or optical wires)
- wireless channels (mobile radio - WiFi, Bluetooth, ZigBee etc.)
- cordless channels (optic laser and infrared connections, ultrasound connection)

▷ Information or data acquisition and monitoring means:

- electro-mechanical sensors (terminal switch, strain gauge)
- electrical sensors (capacitance detector)
- electro-magnetic sensors (induction coil - magnetic field)
- electro-optical sensors (infra LED transmitter - receiver)

For real-time control, the most widespread means are wire communication channels. They enable user to operate with guaranteed high data rates. However, as mentioned, in steadily developed industrial applications containing more and more distributed and moving components, they are limited by their inflexibility and bounded distance. The alternative to them is wireless or cordless solution. It has usually smaller data rates and lower transfer guaranty, but it eliminates the distance bounds and can be flexibly adjusted and reconfigured.

In the following sections, the focus will be taken on wireless ZigBee communication protocol and electro-optical data monitoring as a promising solution for industrial automation.

III. Wireless communication based on ZigBee protocol

ZigBee is a low-cost, low-power, wireless mesh networking proprietary standard of communication protocol. The low cost allows this technology to be widely deployed in wireless control and monitoring applications, the low power-usage allows longer life with smaller batteries, and the mesh networking provides high reliability and larger range. It is able to remain quiescent for long periods without communications and to allow devices to sleep without the requirement for close synchronization e.g. contrary to similar Bluetooth technology.

The ZigBee protocol is intended for use in embedded applications having low data rates and requiring low power consumption. ZigBee's focus is to define a general-purpose, inexpensive, self-organizing mesh network that can be used for industrial control, embedded sensing, medical data collection, smoke and intruder warning, building automation, home automation, etc. The resulting network will use very small amounts of power.

ZigBee is characterized by very low duty cycle, static and dynamic star, mesh or cluster tree networks with up to 65,000 nodes in one network, with low latency available. Individual devices in the network called nodes can play a role of ZigBee Coordinator, Router or End Device. ZigBee network model is shown in Fig. 2. Whole figure represents cluster-tree network including one router as coordinator, a group of separate routers representing mesh network and two indicated areas with several end devices representing star networks.

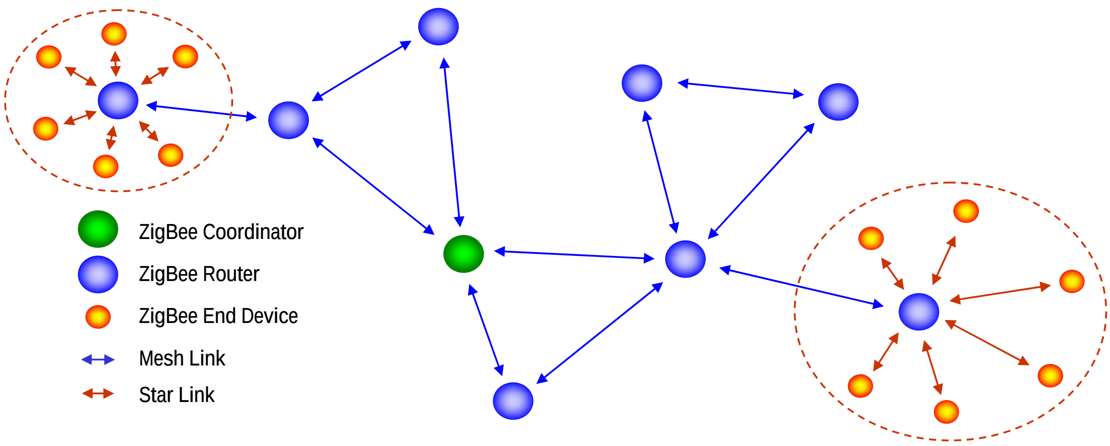

Figure 2: ZigBee network model (network topology)

The role of the coordinator is to set up a network, transmit network beacons (synchronizing signals), manage the nodes and store their information and route messages between paired nodes. It typically operates in the receiving mode. The roles of other network nodes that designed for battery powered or high energy savings, consist in searching for available networks, transferring data from their applications as necessary, furthermore determining whether data is pending and requesting data from the network coordinator. These individual nodes can sleep for extended periods.

The following figure (Fig. 3) shows ZigBee Stack [2]. From ZigBee protocol definition point of view, there are important two layers here: Application layer and Network layer.

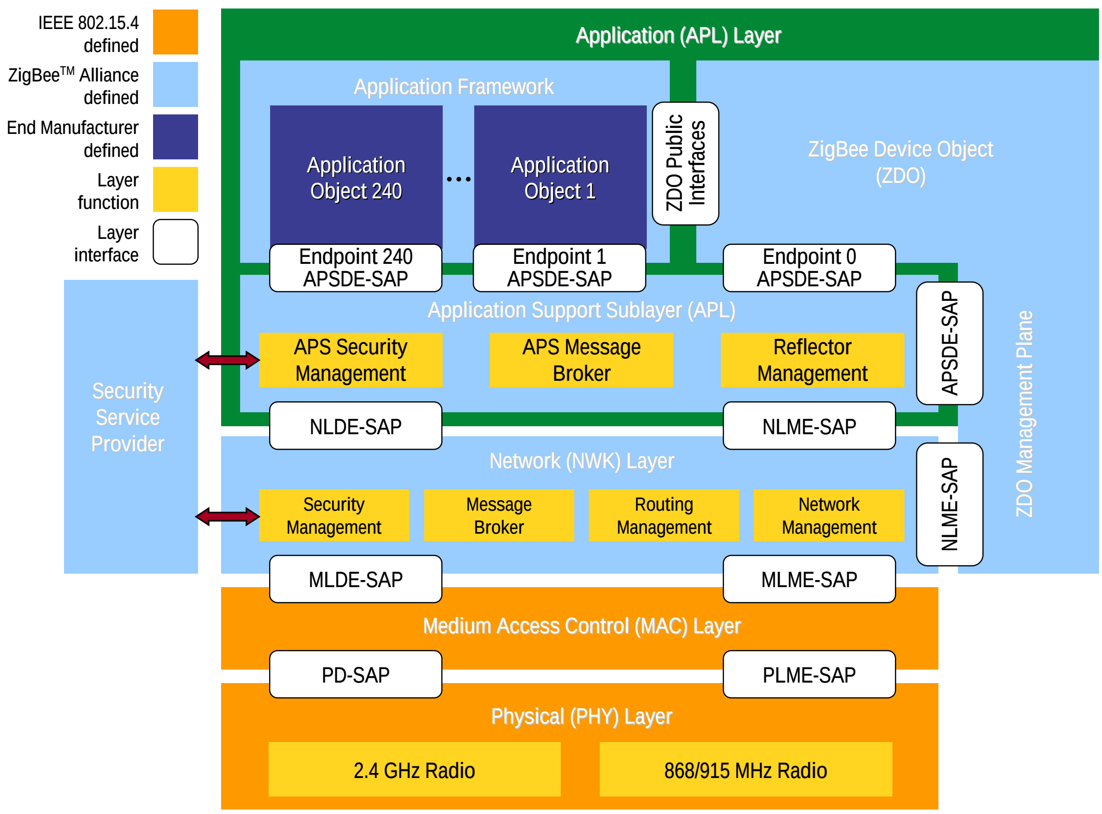

Figure 3: ZigBee Stack (layers of the protocol)

The Application Layer maintains tables for binding, i.e. matching two devices together and forwarding messages between bound devices. It detects other devices operating in the operating space of a device. ZigBee Device Object part defines role of the device within the network (ZigBee coordinator, router or end device), furthermore initiates and/or responds to binding requests and establishes a secure relationship between network devices. The manufacturer-defined application objects implement the actual applications according to the ZigBee-defined application descriptions.

The Network Layer responsibilities include starting a network and successfully establishing a new network, joining and leaving a running network, configuring a new device, by the coordinator addressing of the devices joining the network, device synchronization within a network, applying security to outgoing frames and removing security to terminating frames and routing frames to their intended destinations. The network layer builds upon the IEEE 802.15.4 Medium Access Control Layer's features to allow extensibility of coverage. Additional clusters can be added, networks can be consolidated or split up.

Remaining, the lower layers, Medium Access Control Layer (in this case representing Link Layer) and Physical Layer correspond to standard IEEE 802.15.4-2006 (OSI Reference Model, [3]).

IV. Application example of the wireless communication in the system of several motor units

This section demonstrates wireless ZigBee communication implemented in mechatronic manipulation system (Fig. 4) with several distributed movable units and stationery units. The movable units provide discontinued manipulative operations and the stationary units serve as monitoring and utility interface. Each unit, movable even stationery, is independent of other units (autonomous of others) and is equipped by communication transceiver (transmitter and receiver – all in one). Movable units are driven by their own motors and contain optical positional sensors. The motors and positional sensors are connected with transceivers to the ZigBee communication network.

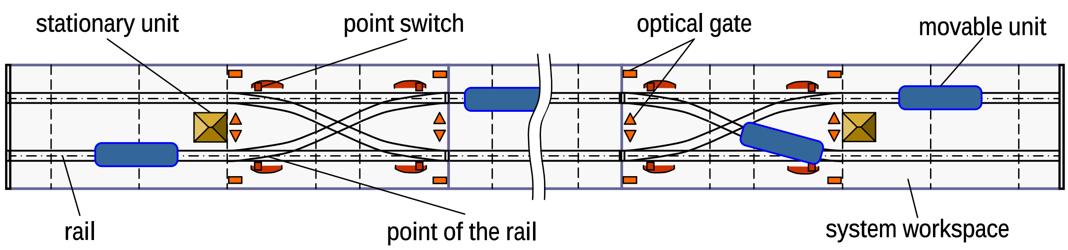

Figure 4: Mechatronic manipulation system

In the network topology point of view (see Fig. 2), this configuration is realized as one star network with one ZigBee router holding also the ZigBee coordinator's function. Individual movable and stationery units represent ZigBee end devices. The ZigBee coordinator is connected via USB interface with a supervising computer. From this computer point of view, the ZigBee communication serves the computer as a very flexibly reconfigurable input-output interface with variable number of various inputs and outputs. The computer provides regularly data exchange with access point to the network (ZigBee coordinator), generates control commands and provides processing and visualization of acquired data from system units.

The following figures show trial hardware realization of individual components.

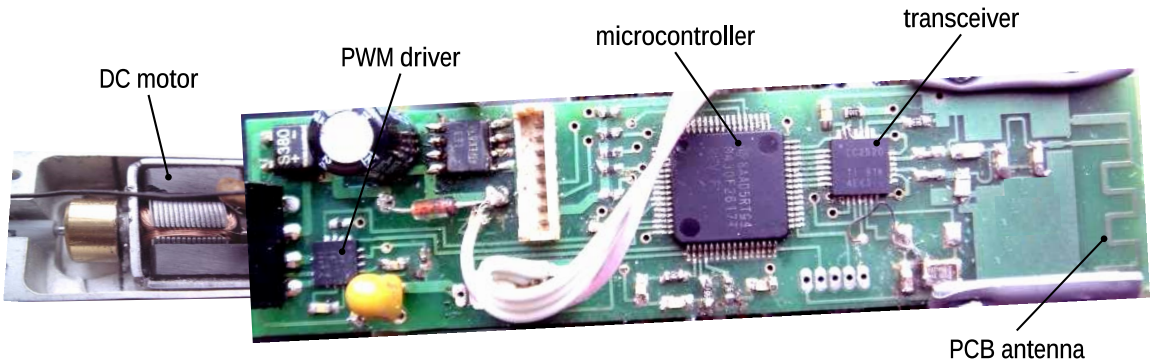

Figure 5: Transceiver and power-drive control in one board

The circuit in Fig. 5 contains microcontroller MSP430F2618 [4], transceiver CC2520 compatible with standard IEEE 802.15.4 [5] and PWM power driver DRV8800 [6] of DC motor, uncovered part of which is visible on the left figure side. On the opposite side, there is a Printed Circuit Board antenna (PCB antenna, monopole) for the transceiver. This circuit follows from development kit CC2520DK used for the prototyping of the wireless communication [7]. However, the final realization in Fig. 5 is moderately adapted due to dimension requirements.

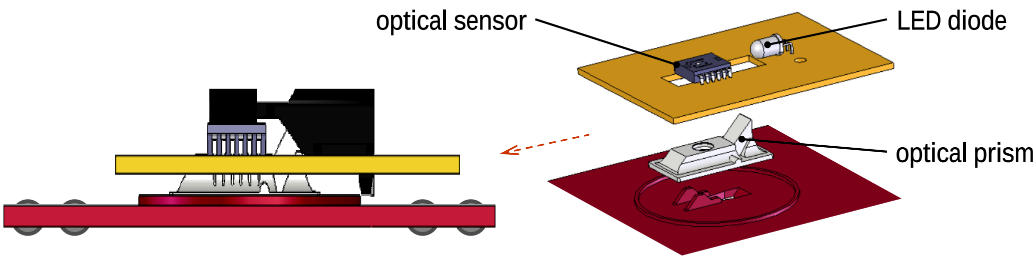

Figure 6: Electro-optical sensor unit for position monitoring

In Fig. 6, there is a vertical assembling disposition of optical sensor PAN3401 [8] including other necessary optical elements. Design and construction of the electronic circuits of the transceiver and sensor unit is described in [9].

The Fig. 7 shows optical infrared gate (emit. diode TSAL6100 [10] and receiver TSOP31236 [11]).

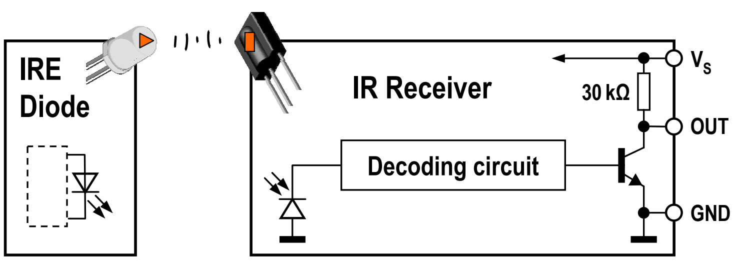

Figure 7: Block diagram of optical gate

V. Prospects of presented wireless communication for real fully-feedback control

Feedback control of real mechatronic systems may be realized with different control approaches. One of them is model-based approach represented by multi-step predictive control and LQ control [12], which offer a solution on global level of whole controlled system even for cases with heterogenous, distributed configurations. The ground of that control consists in comparison of topical value of controlled system output with required value supplemented with comparison of future expected (predicted) values with future required values.

In this regard, control actions in mechatronic systems represent amount of energy, which is necessary for controlled system. ‘Optimal’ control action is searched as smallest as possible, i.e. the minimization of value of assessment criterion. The criterion (cost function) expresses relations among control actions and differences among real, predicted and required output quantities.

The theoretical possibility to involve various control aims corresponding to individual components of controlled mechatronic system in only one criterion or cost function and provide its optimization is very motivating feature of mentioned model-based control representatives. To realize this, it is necessary to have some one unifying means, which form a flexible data concentrator, which provides uniform communication capability among many end devices and one (or more) control system (supervising computer). ZigBee communication protocol is a one advanced communication standard, which can fulfill mentioned aims.

Acknowledgement

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References

[1] Wikimedia Foundation, Inc., *Mechatronics*, May 2010, URL: http://en.wikipedia.org/wiki/Mechatronics.

[2] P. Kinney, “ZigBee Technology: Wireless Control that Simply Works”, *Proc. of Communications Design Conference*, pp. 1–21, Oct. 2003, URL: http://www.zigbee.org/imwp/idms/popups/pop_download.asp?contentID=5162.

[3] IEEE Computer Society, *Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs) IEEE Std 802.15.4-2006*, Institute of Electrical and Electronics Engineers, Inc., 2006, URL: http://standards.ieee.org/getieee802/download/802.15.4-2006.pdf.

[4] Texas Instruments, *MSP430F241x, MSP430F261x Mixed Signal Microcontroller (Rev. F) (Datasheet)*, 2009, URL: http://focus.ti.com/lit/ds/symlink/msp430f2618.pdf.

[5] Texas Instruments, *2.4 GHz IEEE 802.15.4/ZigBee RF Transceiver (Datasheet)*, 2007, URL: http://focus.ti.com/lit/ds/symlink/cc2520.pdf.

[6] Texas Instruments, *DMOS Full-Bridge Motor Drivers. (Rev. D) (Datasheet)*, 2010, URL: http://focus.ti.com/lit/ds/symlink/drv8800.pdf.

[7] Texas Instruments, *CC2520 Development Kit (Users Guide)*, 2007, URL: http://focus.ti.com/lit/ug/swru138/swru138.pdf.

[8] PixArt Imaging Inc., *PAN3401 PS/2 Optical Mouse Single Chip (Datasheet)*, 2008, URL: http://pdf1.alldatasheet.com/datasheet-pdf/view/333238/PIXART/PAN3401.html.

[9] V. Rychnovský, *Wireless Control of Motor Units of Model Railways (in Czech)*, Bachelor’s Thesis. Faculty of Electrical Engineering, Czech Technical University in Prague, 2009.

[10] Vishay Electronic GmbH, *TSAL6100, High Power Infrared Emitting Diode (Datasheet)*, 2009, URL: http://www.vishay.com/docs/81009/tsal6100.pdf.

[11] Vishay Electronic GmbH, *TSOP312.., TSOP314.., IR Receiver Modules for Remote Control Systems*, 2009, URL: http://www.vishay.com/docs/81745/tsop312.pdf.

[12] K. Belda et al., *KBweb - GPC Toolbox*, Institute of Information Theory and Automation AS CR, 2005 - present, URL: http://as.utia.cz/asc/.