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Application of Wireless Protocols Bluetooth and ZigBee in Telemetry System Development

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1. Introduction

The paper presents some investigations in the area of wireless communication and wireless protocols applications. This work is connected with joint research project between Central Laboratory of Mechatronics and University of Trieste – "Development of telemetry system for single cell recording in the avian hippocampus". This project consists of three stages: investigation and choosing a protocol for data transmission; development of a transmitter-receiver system; development of a digital telemetry system.

The main goal of this investigation is to find an appropriate solution for data transmission from avian (or flaying birds) hippocampus. The technology used in the University of Trieste is based on cable connection. It is uncomfortable because the cables are twisting and this obstructs the work. It is important to replace the cables and to give a possibility for free moving. For this purpose, the neural signals should be transmitted in a digital way, after appropriate pre-processing: digitalization and compression. Fig. 1 shows the current method for data transfer. As seen from the figure, the cables are connected from the electrode (from chicken's head) to a recording system (connected to the Personal Computer).

The next items present a general description and application of the newest wireless protocols – ZigBee (IEEE 802.15.4 standard) and Bluetooth (IEEE 802.15.1 standard). Some of the wireless technologies can be an unit as Personal Area Network.

A personal area network (PAN) is the interconnection of information technology devices within the range of an individual person, typically 10 meters [7].

PAN Technologies include the following protocols**:**

- IrDA;
- Bluetooth 802.15.1;

Fig.1. The current solution for single cell recording

- ZigBee 802.15.4;
- Ultra Wide Band 802.15.3a.

The basic advantages of PAN technologies are [7, 8]:

- Short-range;
- Low Power;
- Low Cost;
- Small networks;
- Communication of the devices within a Personal Operating Space.

The paper reviews the state-of-the art of wireless transmission methods and a preliminary study of the development of a hardware/software system for telemetry recording in flying birds.

2. Bluetooth – general information

Founded in February 1998, Bluetooth is a standard developed by the members of the Bluetooth SIG (Ericsson, Intel, Toshiba, Nokia & IBM.) that allows any sort of electronic equipment to make its own connections, without wires, cables or any direct action from an user. Today, more than 1000 companies have joined SIG to work for an open standard for the Bluetooth concept.

Bluetooth is a low-cost, low-power, secure and robust standard for short-range connectivity. The technology has been designed for ease of use, simultaneous voice and data and multi-point communications. It supports a range of 10 m, which can be increased up to 100 m with the use of an amplifier.

Any Bluetooth system has four basic parts [1, 2, 4]: *a radio* (RF) that receives and transmits data and voice; *a baseband* or link control unit that processes the transmitted or received data; *link management software* that manages the transmission; *supporting application software*. The Bluetooth radio is a short-distance, low-power radio that operates in the unlicensed spectrum of 2.4 GHz. This spectrum is shared by other types of equipment (e.g. microwave ovens). In order to avoid interference, the Bluetooth specification employs Frequency Hopping Spread Spectrum (FHSS) techniques. Using a nominal antenna power of 0 dB.m, the range is 10 m (33 feet). Optionally, a range of 100 m (328 feet) may be achieved by using an antenna power of 20 dB.m. Data is transmitted at a maximum gross rate of up to 1 Mb/s. Protocol overhead limits the practical data rate to a little over 721 Kb/s. Interference or being out of range may further decrease the achievable data rate. Baseband is the hardware that turns received radio signals into digital form, which can be processed by the host application. It also converts digital or voice data into a form that can be transmitted using a radio signal. The baseband processor takes care of converting data from one form to another (such as voice to digital data), compressing it, putting it into packets, taking it out from packets, assigning identifiers and error correction information and then reversing the entire process for data that is received. In Bluetooth, the baseband function is called a link controller. The link manager software runs on a microprocessor and manages the communication between Bluetooth devices. Each Bluetooth device has its own link manager, which discovers other remote link managers, and communicates with them to handle link setup, negotiate features, authenticate QoS and to encrypt and adjust data rate on link, dynamically. The application software is embedded in the device that operates an application over the Bluetooth protocol stack. This software allows the PDA, the mobile phone, or the keyboard do its job. All Bluetooth devices must have compatible sections in their Bluetooth stack, so that all Bluetooth devices will be able to inter-operate with each other.

Any two Bluetooth devices that come within a range of each other can set up an ad-hoc connection, which is called a **piconet.** Every piconet consists of **up to eight units**. There is always a master unit in a piconet and the rest of the units act as slaves. The unit that establishes the piconet becomes the master unit. The master unit can change later but there can never be more than one master. Several piconets can exist in the same area. This is called a **scatternet**. Within one scatternet all units share the same frequency range, but each piconet uses different hop sequences and transmits on different 1 MHz hop channels. All piconets share the 80 MHz band, and thus as long as the piconets pick different hop frequencies, no sharing of hop channels occurs[4].

The basic characteristics of Bluetooth are [2, 4]:

- Operates in the **2.4 GHz** band at a data rate of **720 Kb/s;**
- Uses **Frequency Hopping (FH) spread spectrum**, which divides the frequency band into a number of channels (2.402-2.480 GHz yielding 79 channels);
- Radio transceivers **hop** from one channel to another in a **pseudo-random fashion, determined by the master**;
- Supports up to **8 devices in a piconet** (1 master and 7 slaves);
- **Piconets** can combine to form **scatternets.**

Fig. 2 shows two topology schemes – a piconect and a scatternet.

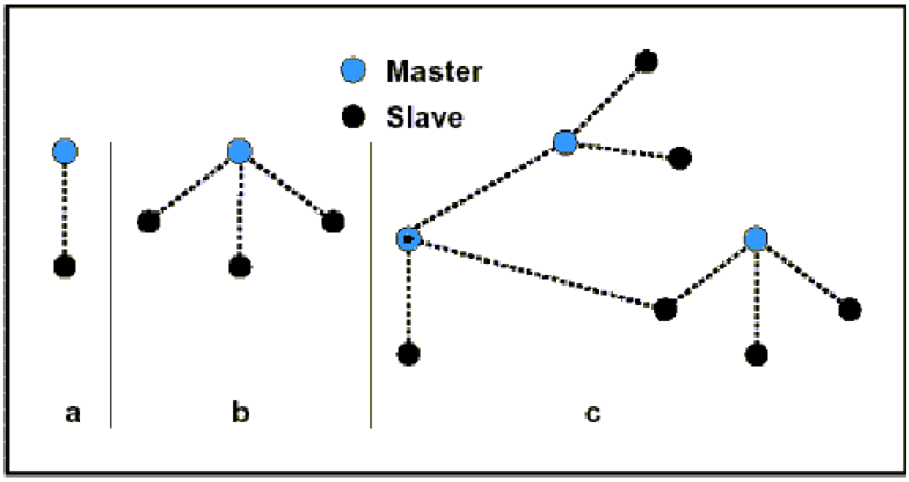

Fig. 2. Topology of: a piconect with one slave device (a); a piconect with several slave devices (b); a scatternet (c).

3. ZigBee – general information

ZigBee standard is managed by the Zigbee Alliance, a global consortium of more than 50 companies (OEMs, IC vendors & tech companies).

ZigBee is a home-area network designed specifically to replace the proliferation of individual remote controls. ZigBee was created to satisfy the market need for a cost-efficient, standards-based wireless network that supports low data rates, low power consumption, security, and reliability [3]. To address this need, the ZigBee Alliance, an industry working group is developing standardized application software on top of the IEEE 802.15.4 wireless standard. The alliance is working closely with the IEEE to ensure an integrated, complete, and interoperable network for the market. For example, the working group will provide interoperability certification testing of 802.15.4 systems that include the ZigBee software layer.

The ZigBee Alliance will also serve as the official test and certification group for ZigBee devices. ZigBee is the only standards-based technology that addresses the needs of most remote monitoring and control and sensory network applications.

Following the standard Open Systems Interconnection (OSI) reference model, ZigBee protocol stack is structured in layers. The first two layers, physical (PHY) and media access (MAC), are defined by IEEE 802.15.4 standard [8]. The layers above them are defined by ZigBee Alliance.

ZigBee-compliant products operate in unlicensed bands worldwide, including **2.4 GHz** (global), **902 to 928 MHz (Americas), and 868 MHz (Europe)**. Raw **data** throughput **rates of 250 Kb/s** can be achieved at **2.4 GHz** (16 channels), **40 Kb/s at 915 MHz** (10 channels), and **20 Kb/s at 868 MHz** (1 channel). **The transmission distance** is expected to range **from 10 to 75 m**, depending on the power output and environmental characteristics [5, 8]. Like Wi-Fi, ZigBee uses direct-sequence spread spectrum in the 2.4 GHz band, with offset-quadrature phase-shift keying modulation. The channel width is 2 MHz with 5 MHz channel spacing. The 868 and 900 MHz bands also use direct-sequence spread spectrum but with binary-phase-shift keying modulation.

Two different device types can participate in a ZigBee network [5, 7, 8]: a **full-function device (FFD);** a **reduced-function device (RFD)**. The FFD can operate in three modes serving as: a personal area *network (PAN) coordinator*; *a coordinator*; or *a device*. An FFD can talk to RFDs or other FFDs, while an RFD can talk only to an FFD.

An RFD is intended for applications that are extremely simple, such as a light switch or a passive infrared sensor; they do not need to send large amounts of data and may only associate with a single FFD at a time. Consequently, the RFD can be implemented using minimal resources and memory capacity.

A system conforming to IEEE 802.15.4 consists of several components. The most basic is the **device.** A device can be an RFD or an FFD. Two or more devices within a Personal Operating Spase (POS) communicating on the same physical channel constitute a Wireless Personal Area Network (WPAN). However, a **network shall include at least one FFD, operating as the PAN coordinator**.

Depending on the application requirements, the Low range Wireless Personal Area Network (LR-WPAN) may operate in either of two topologies: the star topology or the peer-to-peer topology. Both are shown in Fig. 3.

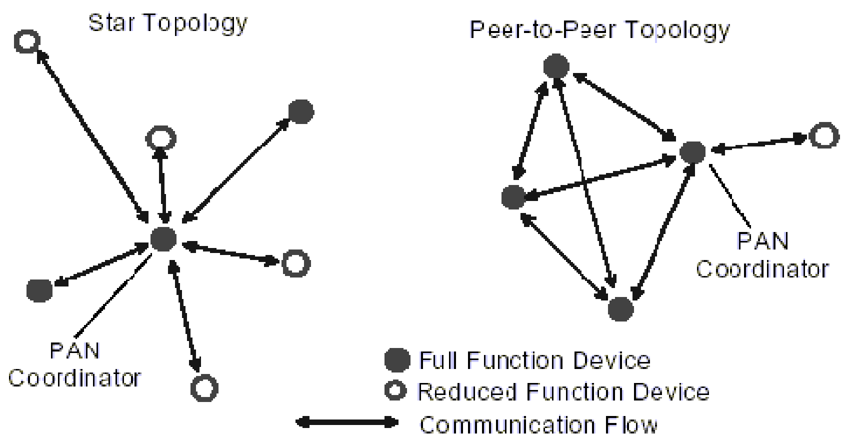

Fig.3. Star, and peer-to-peer topology examples

In the star topology the communication is established between devices and a single central controller [5], called the *PAN coordinator*. A device typically has some associated application and is either the initiation point or the termination point for network communications. A PAN coordinator may also have a specific application, but it can be used to initiate, terminate, or route communication around the network. The PAN coordinator is the primary controller of the PAN. All devices operating on a network of either topology have unique 64-bit extended addresses. This address can be used for direct communication within the PAN, or it can be exchanged for a short address allocated by the PAN coordinator when the device associates. The PAN coordinator may be mains powered, while the devices will most likely be battery powered. Applications that benefit from a star topology include home automation, personal computer (PC) peripherals, toys and games, and personal health care.

The peer-to-peer topology also has a PAN coordinator; however, it differs from the star topology in that any device can communicate with any other device as long as they are in the range of one another. Peer-to-peer topology allows more complex network formations to be implemented, such as mesh networking topology. Applications such as industrial control and monitoring, wireless sensor networks, asset and inventory tracking, intelligent agriculture and security would benefit from such a network topology. A peer-to-peer network can be ad hoc, self-organizing and self-healing. It may also allow multiple hops to route messages from any device to any other device on the network. Such functions can be added at the network layer.

4. Comparison and hardware solution

ZigBee is advantageous for a telemetric system due to low energy consumption and battery life, and wider range. However, it has a relatively limited bandwidth (20-250 Kb/s), which would only be sufficient for a telemetric system with up to eight recording electrodes. In contrast, the bandwidth of Bluetooth (720 Kb/s) is about three times as much as that of ZigBee.

The ZigBee protocol is designed for a greater autonomy (several months) that, however, could be obtained only in case of low-rate data transmission. This is not the case in multi-neuron recording, where neuronal signals should continuously be transmitted, which would drastically increase the energy consumption, hence, reduce the autonomy to several days.

Bluetooth networks have a more limited range than ZigBee networks (10-100 m), which could be problematic for Bluetooth-based systems in cases of experiments in a wide natural environment.

Philips made the following comparison between ZigBee and Bluetooth [7]:

Bluetooth is best for

- Ad-hoc networks between capable devices
- Handsfree audio
- Screen graphics, pictures…
- File transfer

But ZigBee is Better if

- The network is static
- Lots of devices
- Infrequently used
- Small data packets

Peak Information Rate:

ZigBee ~ 128 Kb/s

Bluetooth ~ 720 Kb/s

Timing Considerations

ZigBee

- New slave enumeration = 30 ms typically
- Sleeping slave changing to active = 15 ms typically
- Active slave channel access time = 15 ms typically

Bluetooth

- New slave enumeration ≥ 3 s
- Sleeping slave changing to active = 3 s typically
- Active slave channel access time = 2 ms typically

The table from Fig. 4 summarized the comparison between Bluetooth and ZigBee.

As a conclusion it can be said that ZigBee and Bluetooth are two solutions for two application areas.

Commercial Bluetooth solutions are available as fully self-contained transceiver modules. They are designed to be used as add-on peripherals. They feature an embedded CPU, different types of memory, as well as baseband and radio circuits.

A multi-channel digital telemetry system needs to digitalize and process a number of analogical signals, which nowadays are implemented in a one-chip microcontroller that integrates: an analog-digital converter (ADC); digital signal processing and temporal storage in working memory (RAM), and a digital interface to the transceiver device.

In Fig. 5 a list is provided of few microcontrollers that could be perspective for this purpose: AT90LS8535, ATMega128L (produced by Atmel), PIC16F8X (by Microchip), and MSP430F149 (by Texas Instruments).

System	ZigBee™ 802.15.4	Bluetooth™ 802.15.1
Application	Monitoring and control	Cable replasment
System resources	4-32 KB	250 KB
Battery life (days)	100-1000+	1-7
Nodes in network	255 / 65K+	7
Baseband(Kb/s)	20-250	720
Distance (meters)	1-75+	1-10+
Key characteristics	stabitity, low consumption, low cost	price, easy to use comfort

Fig 4. Comparison between Bluetooth and ZigBee

Characteristic	AT90LS8535	ATmega128L	PIC16F8X	MSP430F149
Bits	8	8	8	16
Flash (bytes)	8 K	128 K	68 K	60 K
RAM (bytes)	512	4 K	1 K	2 K
ADC	8×10 bit	8×10 bit	–	4×12 bit
Timers	3	3	1	3
Voltage	4-6 V	2.7-5.5 V	2-6 V	1.8-3.6 V
Active power	6.4 mA	5.5 mA (4 MHz)	2 mA	400 uA
Idle power	1.9 mA	2.5 mA (4 MHz)	–	1.3 uA

Fig. 5. Microcontroller devices

Analyzing the characteristics of the microcontrollers (MCUs) shown above, it could be concluded that ATmega128L is most suitable for the telemetry system.

In summary, the proposed hardware solution has the following characteristics:

- ♦ MCU: Atmel ATmega128L;
- ♦ Memory (Built in): 4 K SRAM, 128 K Flash, 4 K EEPROM;
- ♦ External memory: 64 K RAM (optionally);
- ♦ ADC: 8 Channel 10 bit A/D-converter;
- ♦ Serial communication: 2 programmable serial UARTs.

5. Conclusion

This article presents preliminary investigations for the realization of the communication module of an improved telemetric system that would allow multi-neuron recordings in completely unconstrained animals. Radiotelemetry has been used in bio-medical sciences for wireless transmission of data, but previous systems have been based upon analogical transmission only that allowed the transmission of up to two channels.

For data transmission, the paper suggests that the so-called Personal Area Networks (PAN) wireless technology devices could be appropriate, because they allow low-energy, large-band interconnection within the range of 10-100 m. In the article two of the most promising wireless PAN-protocols are reviewed that could be used for the implementation of such a system: ZigBee and Bluetooth.

It also investigates prospective microcontrollers that would pre-process the data and communicate it to the Bluetooth device. Size, energy consumption, and number of the on-board and allowed external ADC were among the main criteria. Atmel ATmega128L processor is the most appropriate for this purpose.

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Применение беспроводных протоколов Bluetooth и ZigBee в проектировании системы телеметрии

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(Р е з ю м е)

В статье исследуется коммуникационный модуль системы телеметрии. Рассмотрены два из самых обещающих протоколов организации беспроводной персональной сети связи (Personal Area Network, PAN), вместе с их общими характеристиками и топологическими схемами. Исследованы перспективные для реализации коммуникационного модуля микроконтроллеры. Работа проводится в связи с совместным исследовательским проектом между Центральной лабораторией мехатроники и приборостроения Болгарской академии наук и Университетом города Триеста, Италия.