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Chaotic Transceiver Platform for Multimedia Sensor Networks

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Abstract–The requirements imposed on transceiver devices for transmission of multimedia data in wireless sensor networks and characteristics of the existing systems are considered. Prospects of the use of ultrawideband systems based on direct chaotic data transmission in multimedia wireless sensor networks are analyzed. The results of experiments on "point-to-point" streaming video transmission are presented, including relay and through-the-wall transmission.

1. Introduction

Wireless sensor networks (WSN) can be considered a part of the paradigm called the Internet of Things [1]. The basic idea of this paradigm is that objects or things interact and cooperate with each other through wireless communication to address common goals. These objects can be RFIDs, sensors, actuators, mobile phones, etc.

Wireless Multimedia Sensor Networks (WMSN) are a class of WSN whose nodes are equipped with multimedia sensory devices such as video cameras or microphones, and are able to retrieve from the environment video and/or audio streams, images, in the same way as the scalar sensory data is recovered by conventional WSNs.

Opportunities of WMSN attract considerable attention of both researchers and industry [2-3]. WMSNs have wide area of potential civil and military applications, in which acoustic and video information is required. Examples include surveillance sensor networks, monitoring of industrial plants and environment, intelligent traffic management, personal health sensor means, digital multimedia entertainment, etc. In all these applications, multimedia content allows us to raise the qualitative level of collected information compared with only scalar data measurements.

In the process of developing and using WMSN new problems arise in addition to those of conventional WSN. They are associated with the nature of multimedia data: necessity of real-time data transmission, high bandwidth requirements for communication channels, admissible time delays and loss of quality of information transmitted from the source to the consumer. These problems must be solved under severe restrictions on energy consumption, memory and processing capabilities.

The physical level of communication stack that is analyzed in this report is very serious for multimedia sensor networks as the volumes of produced and transmitted data can greatly exceed the volume of data circulating in usual WSNs. However, it is usually not discussed in detail, since the majority of development is based on ZigBee wireless technology, which dominates the market of sensor networks. (In autumn 2013, companies offer more than 50 models of wireless sensor nodes [4] and, with rare exceptions, they use wireless connections based on IEEE 802.15.4 standard.)

The rate of point-to-point data transmission/reception with ZigBee nodes is no more than 250 Kbps (in network environment it is still several times less), which significantly limits capabilities of ZigBee multimedia networks. Other common radio technologies (Wi-Fi, Bluetooth) have their own basic limitations that prevent their use in WMSN.

To solve the problem of creating an effective radio with significantly greater bandwidth than ZigBee, we suggest to use chaotic UWB communications [5, 6]. A prototype of multimedia wireless sensor node comprising a chaotic transceiver and a video module, principles of its operation and its features are described. Operation of the created prototype in different modes ("point-to-point", relay, transmission through the wall) is investigated experimentally.

2. State of the art

Typical node of wireless multimedia sensor network consists of a sensor (S) (video, audio), a processing unit (PU), a control unit (CU) and a transceiver (T) (Fig. 1).

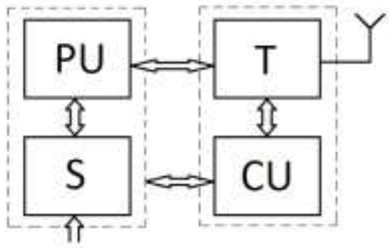

Fig.1. Block diagram of WMSN node.

Below, by "platform" we shall understand the node without sensor. The existing platforms for WMSNs can be divided into three groups [2]:

1) Light platforms: devices originally designed to operate with scalar data such as temperature, light, humidity, etc. The main requirement is to consume as little energy as possible. Hence, these devices have low processing power and small storage capacity. Most of them use 2.4 GHz transceivers with physical layer of IEEE802.15.4 standard (chip CC2420 [7] or similar). CC2420 consumes 17.4 mA in transmit mode and 19.7 mA in receive mode. Maximum emission power is 0 dBm for data rate of 250 Kbps. Light-class nodes are represented by MicaZ [8] and FireFly [9].

2) Middle devices: higher ability to process information and lots of memory in comparison with light devices. However, they are also equipped with narrow-band low-bitrate transceiver modules, i.e., use the same physical layer as the light-class devices. Examples: Tmote Sky [10] and TelosB [11].

3) Heavy platforms: the most powerful in terms of performance and computational capabilities; designed for fast and efficient processing of multimedia information. Able to use variety of operating systems (e.g., Linux, TinyOS, run Java applications and .NET micro frameworks) and maintain radio communication using different physical layer technologies (e.g., IEEE 802.15.4, IEEE 802.11 or Bluetooth). However, such a platform consumes relatively much power (> 0.5 W). Examples: Stargate and Imote2.

Processing unit of Stargate [12] has powerful processor, large memory and runs under Linux. It can be interfaced with Mica2 or MicaZ for wireless communication under IEEE 802.15.4 and 802.11 or with Bluetooth modules. Imote2 [13] is a full platform with a processing unit and a transceiver; can run various operating systems. Imote2 was used in [14] for image transmission over wireless sensor network; consumes 66 mA in active mode.

Analysis of prototypes of wireless sensor nodes and networks reveals two main approaches:

- Basic processing of sensor data is provided by the sensor node and the results in the form of short messages is sent over the network to the root node (processing center).

- The node performs primary data processing, e.g., compression, and significantly smaller data volume is sent over the network than it was originally produced by sensors. However, these volumes are much greater than the typical data flows of scalar-data sensor networks.

In the first case, if the total data stream from the network nodes does not exceed several tens of Kbps, ZigBee technology can be used quite effectively.

In the second case, when the data streams comprise hundreds of Kbps or more, alternative wireless solutions are necessary.

Another problem is efficient use of battery power in order to increase battery life by means of sharing it between PU and transceiver. The deeper the data processing, the more energy consumes the processing unit. On the other hand, the better the information compression, the less data flow is transmitted and, consequently, the less energy consumption of the transceiver.

An example of sensor node with effective combination of compression and transmission is given in [15], where a transceiver with data rate up to 1 Mbps is used.

3. Multimedia sensor network requirements

The main feature of WMSN in respect to classical WSN is large amount of input data received by network nodes from sensors. This applies to both video and audio sensors. In the case of video sensor, input data volumes can range from tens of Kbps for periodic low-resolution images to hundreds of Mbps for HD video camcorders with 60 fps and higher. The inflow rate of digitized acoustic data can vary from 10 Kbyte/s (human voice) to 100 Kbyte/s (high-quality music) and more.

Sensor data must be processed directly in the sensor node in order to dramatically reduce the amount of information transmitted over the network. This processing may be aimed at data compression (usually with losses) with subsequent recovery of images or sound in the root node, or at the extraction of essential features of the input data, e.g., registering certain events.

To estimate requirements for network transmission rate, consider a node with a VGA camera (640 × 480 pixels × 2 bytes). This frame contains approx. 0.6 Mbyte of data. If per-frame compression is used, e.g., JPEG, then the data volume for one frame is reduced 20-30 times down to 20-30 Kbyte/s (160-240 Kbps). Thus, if the channel capacity is ~ 1Mbps, theoretically it can transfer 4-6 fps. In the case of QVGA (320×240) frames with the same compression ratio and the same PHY, the number of frames transmitted per second can be increased to 16-24.

The above discussion refers to "point-to-point" communication. In complex-topology WMSNs the maximum possible transmission rate (at a fixed PHY rate) is much lower.

Let us consider two simple, yet basic topologies.

1. **"Star".** The network includes a root node and n video sensors which transmit information to the root. Physical data rate of sensor node transceivers and the root node is C. Then each sensor node can transmit data to the root with the rate (average) no more than $C_{av} = C/n$.

2. **Network with relay.** The network includes a root node, a sensor node and a relay (repeater). All transceivers have physical rate C. What is actual rate with which the sensor node can transmit data? After transmission of the first packet of duration T_p it must wait until the repeater processes the packet (which takes T_{proc}) and sends it to the root node (T_p). The total time of packet transmission thought network is

$$T_{tot} = 2\,T_p + T_{proc},$$

where T_{proc} can be equal to (0.5–1.0) T_p. This means that actual transmission rate in such-topology network is C_n

$$C_n = (0.3\text{–}0.4)\,C.$$

Thus, for any network topology, except "point-to-point," actual data rate is essentially lower than the physical rate. Transmission of several low-resolution frames per second in "point-to-point" topology requires at least 100–200 Kbps transmission rate, which means that low bitrate devices, such as ZigBee, cannot be used. Minimum admissible PHY rate for video networks is $C > 1$ Mbps.

4. Direct chaotic data transmission technology

Direct chaotic communication scheme was proposed in IRE RAS in 2000 [5, 6]. In this scheme, information bits are transmitted with chaotic radio pulses, i.e., fragments of chaotic oscillations. Chaotic oscillations with bandwidth more than 500 MHz are generated directly in microwave frequency band. The spectrum of chaotic radio pulse is close to the spectrum of the original chaotic oscillations, if the pulse is not too short.

In 2007 this technology, a joint proposal of Kotelnikov IRE RAS and Samsung Co., was adopted as optional solution in IEEE 802.15.4a standard for WPANs [16]. In the beginning of 2012, a novel IEEE 802.15.6 standard for wireless body area networks was accepted [17], where direct chaotic communication technology is now one of the mandatory solutions.

There are several reasons to use ultrawideband direct chaotic communication technology in wireless multimedia networks:

1. New unoccupied unlicensed frequency band (3.1 to 10.6 GHz [18], in Russia 2.85 to 10.6 GHz).
2. High (for WSN) channel capacity. Due to the use of chaotic signals, the pulse duration can be varied in a wide range with practically no effect on the form of the pulse spectrum. Point-to-point physical bitrate of existing species of direct chaotic transceivers is as high as 6 Mbps, and it can be increased to 24 Mbps and more.
3. High energy efficiency. High physical rate and lower actual (useful) data rate allows to use sleep modes. Hence, the transceiver spends most of its time in a sleep mode, which essentially decreases power consumption.
4. Immunity to multipath fading. Chaotic oscillations are nonperiodic, with rapidly decreasing autocorrelation function, and are barely subject to interference.

To study practical aspects of the use of direct chaotic transceivers in multimedia sensor networks and to quantitatively estimate its efficiency, an experimental wireless video sensor node was designed and tested in some simple-configuration networks.

5. Video sensor node

The designed node layout is shown in Fig. 2. VGA CMOS camera ADCM-2700 is used as video sensor. It produces video stream of 60×40 to 640×480 at 1-60 fps and 1-3 byte color depth (no compression). Power consumption of the camera is 24 mA at 176×144 pixel frame and 10 fps rate. In the designed node, the camera parameters were set at 176×144 pixel frame and 2 byte color depth. Data stream is the number of pixels by color depth by frame rate. Transmission of 1 frame with this parameter set requires 50 Kbytes of data.

The camera interacts with the transceiver through a specially designed processing unit based on STM32 microcontroller (MCU), fabricated as an extension board to the transceiver. Data from camera is transferred to the processing unit using BT.656 standard, and the processing unit is configured (setting image size, color depth, image output format, etc.) with I2C bus.

Video sensor (Fig. 2) is equipped with 3-5 GHz chaotic transceiver PPS-43. Maximum physical data rate of this device is 6 Mbps. Transmission range 25 m. Network functions are controlled by MCU of the transmitter.

Data acquisition center of the network includes a computer and a chaotic transceiver PPS-42 with USB2.0 interface used as a base station. PPS-42 physical data rate is up to 24 Mbps. Data exchange rate between PPS-42 and computer is up to 240 Mbps.

In experiments on video transmission, physical data rate was set at 3 Mbps. Actual data rate is determined by the rate of packet sending.

Fig. 2. UWB wireless video sensor node.

6. Experiments

Four groups of experiments were made:

1. "Point-to-point," distance 2-3 m.
2. Changing the distance from 1 to 25 m.
3. Relay ("chain" topology).
4. Through the wall.

The aim of the first experiment was to test the efficiency of the developed device and algorithms, and to assess image quality and to estimate frame refresh rate.

For radio transmission, each video frame was cut into 128-byte fragments, data packets were formed and transmitted. The frame rate was 2, which corresponded to actual data rate of 800 Kbps.

In the experiment, the hardware was debugged and stable wireless transmission of video data was demonstrated.

The second experiment was carried out in a long corridor of a brick building. The corridor was 45 m (L) × 4 m (W) × 5 m (H). The task was to determine the maximum communication range and the character of image degradation with increasing distance. The first transceiver with video sensor (transmitter) was located at a fixed point of the corridor. The second transceiver connected to laptop (receiver) was moved along the corridor. Measurements were made every meter.

Images received in the experiment at various distances between the transmitter and receiver are shown in Fig. 3. If the distance is less than 15 m (Fig. 3a), the picture is stable and clear with, perhaps, a few corrupted pixels, which generally doesn't affect perception and object recognition. Bit error rate (BER) is less than 10^{-6}.

With increasing distance the signal quality deteriorates. Stripes appear that distort the picture, but the objects in the image are still recognizable (Fig. 3b). At a distance of 25 m the number of errors becomes large, BER reaches 10^{-4} and image quality drops dramatically (Fig. 3c).

In the third experiment, transmission of video data over WMSN was investigated on a network composed of a video sensor node, a repeater node and a base station.

The sensor node (transmitter) is located in a fixed point of the corridor. The repeater is located at a distance of 5 m.

The base station is moved along the corridor. Within the range of 3 to 15 m between the base station and the repeater, the received frames were steady with only few distortions.

In the fourth experiment, through-the-wall transmission of video data was investigated. The sensor node was positioned at one side of a 1-m thick brick wall at a distance of 50 cm from the wall and the receiver was placed at the other side at a distance of 2 m from the wall.

The resulting images are shown in Fig. 4. As can be seen, clear and stable picture is received.

a)
b)
c)

Fig. 3. Video frame recovered on receiver side. The distance between transmitter and receiver is (a) 15 m, (b) 20 m, (c) 25 m.

Fig. 4. Video frame recovered on receiver side. Transmission through the wall.

7. Conclusions

Preliminary estimates show that the use of transceivers based on ultrawideband chaotic radio enables transmission of multimedia information in wireless sensor networks of different topologies and with much lower power consumption than the existing narrow-band solutions.

To verify these estimates, a wireless sensor node with a video module was designed and investigated experimentally. Actual "point-to-point" transmission rate of video data of at least 800 Kbps was shown for 3-Mbps physical data rate. The same data rate was shown in a network with relay (repeater) that corresponds to the actual data rate of 1600 Kbps in the "point-to-point" topology.

Power consumption of the transceiver in transmission mode is about 12 mA, and in the relay mode about 27 mA.

The use of ultrawideband chaotic radio pulses as information carrier allows increasing the rate of transmission of multimedia data in light- and medium-class sensor networks and expanding the range of their tasks.

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