Dependence of Transfer Time of Bluetooth Payload Packets on the Surroundings and Distance

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Abstract. *This paper deals with the Bluetooth technology in telecommunication networks. The basis for the data transmission is a packet which has its own specifics in the wireless communication. The signal level is of higher importance, but other parameters like transfer time and a number of transferred packets are interesting too. The output of this paper is a proposed mathematical model, which describes dependencies of this output parameters on the distance between communicating devices and on the environment, in which these devices are placed. Some input criteria and conditions are defined for the functionality of the proposed design. The file transfer speed between the devices depends on the distance between them and on the surroundings, where the slave device is placed. For our purposes some possible surroundings that might be encountered were selected. It is free-space, paper with variable thickness, PVC or leather and wood with their respective density. Thanks to the application of the logarithmic regression on the output data the equation of mathematical model was found.*

Keywords

Bluetooth, environment, mathematical model, regression, transfer time.

1. Introduction

The basic parameters in information technologies are transmission parameters. Transmission parameters influence the ways of usage of this technology in specific applications. The Bluetooth technology belongs to PAN (Personal Area Network) networks. Their coverage and utilization are determined for applications as the data transmission among personal terminals or the configuration and control of various peripherals.

In the introduction are shortly presented the Bluetooth technology features. The basic for the data transmission is a packet which has its own specifics in the wireless communication. Some packets carry payload data, some packets synchronize and control the communication. This article is focused on data transmission features of the packets that carry useful data.

The possibilities and the utilization of the proposed model are tested in the next part of the paper by comparing results from a mathematical model and the experimental measurements.

Related works [6], [7], describes basic parameters of Bluetooth technology and presents measurement of file transfer delay with variable file size and variable distance with and without physical obstacle. This article is discovered specific parameter – transfer time of payload packets (it means packets with useful information no synchronize and service packets) – of Bluetooth technology in defined condition depend on surroundings and distance by transmitting the same file size data.

2. Feature of Bluetooth

The basic features of Bluetooth technology are frequency range, TX power and RX sensitivity. We overview some specific feature of Bluetooth technology in this chapter.

2.1. Indoor Propagation Mechanism

When radio waves strike a surface that is neither a perfect insulator nor a perfect conductor (in other words, all practical surfaces), part of the wave energy passes through, part is absorbed and part is reflected [8]. These characteristic give us the four paths by which a radio frequency signal can travel from a transmitter

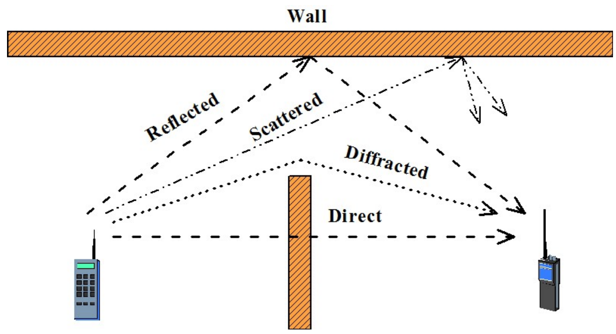

Fig. 1: Types of waves [1].

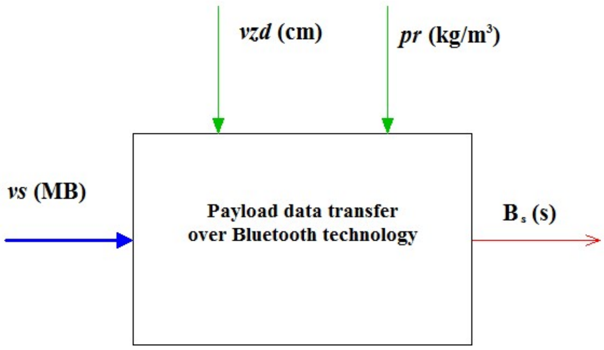

Fig. 2: Mathematical model.

to receiver. The paths are direct, reflected, diffracted and scattered (Fig. 1), [1], [5].

The classic free-space link budget equation is given by:

$$P_r = P_t \cdot G_t \cdot G_r \cdot \left(\frac{\lambda}{4\pi d}\right)^2, \quad (1)$$

where P_r is received signal power, P_t is transmitted power, G_t is the gain of the transmit antenna in the direction of the received antenna and G_r is the gain of the receive antenna in the direction of the transmit antenna. The carrier wavelength λ is 0.122 m at 2.45 GHz and d is the distance (m) between transmitting and receiving antennas [1], [2].

2.2. System Parameters

The Bluetooth technology belongs to PAN (Personal Area Network) networks and their coverage and utilization are determined for applications as the data transmission among personal terminals or as a configuration and control of various peripherals. The Bluetooth devices are small and their range is usually up to 10 meters, for example mobile phones, PDA, mouse or keyboard are typical Bluetooth devices. Important factor of functionality is surroundings where these devices are placed [4].

For the mathematical model of data transmission by Bluetooth technology are distance and surrounding system parameters.

3. Mathematical Model

The mathematical model of data transmission describes communication between two devices. First master device sent data to second slave device. The file transfer between both devices depends on the distance between communicating devices and on the surroundings, where the slave device is placed. For our purposes were selected some possible surroundings that might be encountered, it is free-space (density 1.204 kg/m^3), paper with variant thickness (density 700–1000 kg/m^3), PVC or leather (density 1200 kg/m^3), and wood (density 1000 kg/m^3).

The Bluetooth technology is packet oriented. During a transfer the several types of Bluetooth packets – payload packets, synchronizing packets, control packets or error packets are sent. This paper is oriented only on payload packets – packets with useful information. This idea originated during experiments with Bluetooth protocol analyzer.

With regard to complicated mathematics that describes signal propagation regressed form for creating the mathematical model is used [3]. Parameters of the mathematical model are distance between communicating devices and environment, where a slave device is placed. Used mathematical model of data transfer in Bluetooth technology is depicted in Fig. 2:

- input value: vs (MB),
- parameters: vzd (cm) and pr (kg/m^3),
- output function: B_s (cm).

3.1. Output Function

Data transfer was used in the experiment for compilation of the output function between master and slave devices. For all experiments was used the same file, the same master position and the same slave device. Measured data from Bluetooth protocol analyzer were sorted by direction and packets – only master-slave transfer and only payload packets.

3.2. Measuring Workplace

Measuring workplace illustrated in Fig. 3 shows the basic configuration of the experiment. Bluetooth device

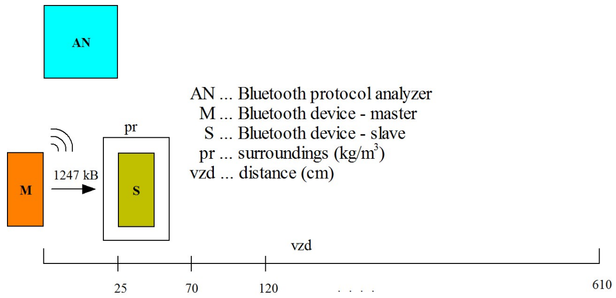

Fig. 3: Measuring workplace.

M sends data to device S in eleven distances, both devices master and slave are on class 3 (power 1 mW, 0 dB).

Transferred data was file (digital picture) with size of 1247 kB (1.217 MB). The experiment was implemented in real conditions for ordinary used Bluetooth applications. As a surroundings parameter were chosen air without obstruction, paper (thickness 2 and 4 mm), plastic obstruction (PVC) and wood. Every obstruction was in the box shape around slave device and experiment room was without special adjustment (obstruction, noise).

Input into the mathematical model was data file in MB, parameters were distance vzd (cm) and surroundings pr (kg/m^3). The density of the air at 20 °C is 1.204 kg/m^3, paper with a thickness of 2 mm have density of 700 kg/m^3, paper with 4 mm have density of 900 kg/m^3, wood have density of 1000 kg/m3 and plastic (PVC) have about 1200 kg/m^3. Output of the mathematical model calculates average transfer time (s) in the dependence on the distance and obstruction surroundings.

4. Experiment

A table of measured data is needed to acquire a determination of dependencies (Tab. 1). First set of measurements was achieved with constant surroundings parameter – dependence of data transfer time on distance between Bluetooth devices. The second set of measurements was achieved with constant distance parameter – dependence of data transfer time on surroundings of slave Bluetooth device.

Measured data was used to create of partial mathematical equation by parametric regression analyse [3]. For graphical data output of time of transferred packets were established functions $B1$ and $B2$, where $B1$ (Fig. 4) is a function of distance with environment parameter (5 colour curves) and $B2$ (Fig. 5) is a function of surroundings with distance parameter (11 colour curves):

Tab. 1: Table of measurement data.

vzd (cm)	**pr (kg/m^3)**				
	1.204	**700**	**900**	**1200**	**1000**
25	77.06	72.74	77.96	80.17	77.54
70	78.26	81.41	90.54	84.64	79.13
120	82.49	88.58	80.20	87.37	81.40
170	92.86	90.57	89.27	86.97	86.48
220	89.16	94.38	88.47	90.43	102.30
270	92.99	91.84	94.47	103.00	89.51
320	98.75	101.15	103.00	103.13	100.16
270	99.16	93.98	93.65	105.67	97.17
450	95.50	105.46	96.98	109.10	108.06
510	96.80	101.09	104.30	108.06	110.35
610	104.22	98.90	104.99	111.96	94.10

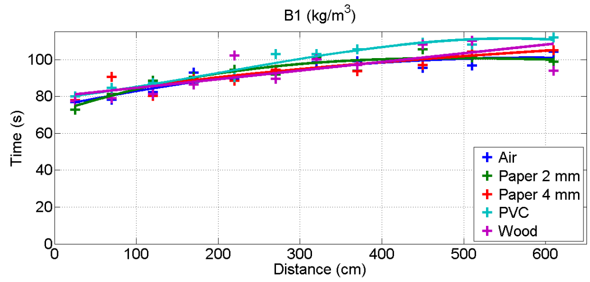

Fig. 4: Time of transferred packets depending on distance.

$$B1 = f(vzd)\,pr$$
$$B2 = f(pr)\,vzd. \quad (2)$$

Equation of output function for data transfer time is:

$$B_s = \frac{vs}{1.217} \cdot k_s \cdot B1 \cdot B2, \quad (3)$$

where B_s is output valuation of time of transferred packet from mathematical model and k_s is coefficient of the mathematical model.

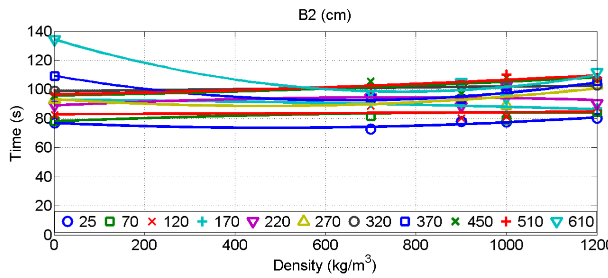

Fig. 5: Time of transferred packets depending on surroundings.

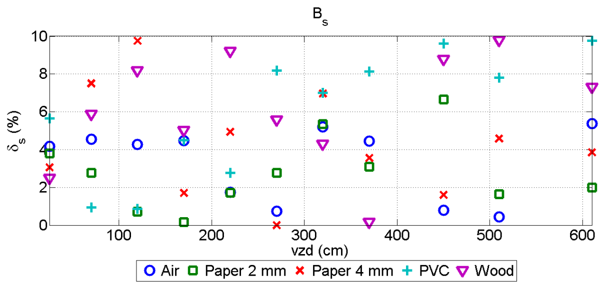

Fig. 6: Relative error.

4.1. Equation of Mathematical Model

Thanks to the application of logarithmic regression analysis on graphical output was found out the equation of a output function of the mathematical model. Because partial equations were multiplying, it is multiplicative (additive) regression model.

For a creation of equation it was needed to select referential point from graphical output from the middle of the graph – parameter vzd is 270 cm and parameter pr is 900 kg/m^3. Distance about 270 cm seemed as a typical distance for Bluetooth applications. It was the same in case of surroundings parameter, selected from the middle. Equation for $B1$ ($B2$) was created from referential point and function by logarithmic regression analysis:

$$B1 = 7.9938 \cdot ln\,(vzd) + 50.329, \tag{4}$$

$$B2 = 0.3287 \cdot ln\,(pr) + 92.552. \tag{5}$$

The constant k_s were needed to calculate from the mathematical model:

$$k_s = \frac{B_{(270.900)}}{B1 \cdot B2} = 0.010482, \tag{6}$$

where $B_{(270.900)}$ is 94.47. In Fig. 6 is shown the final form of the mathematical model of Bluetooth technology data transmission. Final output equation:

$$B_s = \tfrac{vs}{1.217} \cdot 0.010482\,(7.9938 \cdot ln\,(vzd) + 50.329) \cdot \cdot (0.3287 \cdot ln\,(pr) + 92.552)\,. \tag{7}$$

5. Conclusion

Created mathematical model describes dependencies of the output parameters – transfer time of payload packets – on the distance between communicating devices and on the surroundings, where these devices were placed. Some input criteria and requirements were necessary to define the functionality of the proposed model.

For verification of the mathematical model of Bluetooth technology data transmissions the output equation was applied to all measurements and values from experimental measurement were compared with values from the mathematical model. The relative error δ_s was also determined:

$$\delta_s = \left[\frac{\Delta x}{x}\right] = \left[\frac{B_m - B_s}{B_m}\right], \tag{8}$$

where B_m is value from experiment measurement.

Total evaluation of issues of the mathematical model can be considered acceptable, because experiments and mathematical model were created for real conditions. The results of relative errors were about 5 %. It means that measurement data can be influenced by ordinary interferences and noises. The mathematical model does work the best for Bluetooth devices in class 3 in the range from 100 to 500 cm. Bluetooth functions and applications services were conformed to this range.

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