2019 IEEE International Scientific-Practical Conference

Problems of Infocommunications Science and Technology

(PIC S&T `2019)

Conference Proceedings

October 8-11, 2019
Kyiv, Ukraine

Kyiv
2019

2019 IEEE International Scientific-Practical Conference
Problems of Infocommunications. Science and Technology

PIC S&T `2019

Organized by

Institute of Electrical and Electronics Engineers, Inc.

Kharkiv National University of Radioelectronics

Borys Grinchenko Kyiv University

Technical Co-Sponsorship

Ukraine (Kharkov) Section SP/AP/C/EMC/COM Joint Chapter

Papers are presented in author's edition

IEEE Catalog Number: CFP19PIA-ART
ISBN 978-1-7281-4184-8

CONTENS

Models of Information Processing in IoT Networks on the Basis of Fundamental Trigonometric Splines

Viktoriia Onyshchenko, Olena Negodenko
State University of Telecommunications
Kyiv,Ukraine
oviva@ukr.net, negodenkoav@i.ua

Svitlana Shevchenko
Borys Grinchenko Kyiv University
Kyiv Ukraine
s.shevchenko@kubg.edu.ua

Abstract. **The approach to increase the efficiency of information processing in wireless networks on the basis of the proposed mathematical model is considered. This model is based on fundamental trigonometric splines. The construction of trigonometric splines is shown, as well as the smoothness properties of trigonometric splines, which are important at the stage of construction of these models. The method of the information signal reproduction in the communication system by interpolation of the digital signal, using the fundamental trigonometric spline is proposed. It has been shown that the use of trigonometric splines will allow the reproduction of information signals with less error. The estimation of the complexity of the algorithm for constructing trigonometric splines is compared with the existing ones. An important scientific problem was solved, which consists in improving the methods of information processing in the Internet of Things based on fundamental trigonometric splines.**

Keywords. Internet of things (IOT), information signal, fundamental trigonometric spline, complexity of the algorithm.

I. INTRODUCTION

In the modern world, information processing, sharing and protection are the priority areas for the development of any society.

A special place in modern information technologies is held by the Internet of things concept.

The concept and the term for it were first formulated in the USA in 1999. And in 2008, the concept gained worldwide significance when the number of devices connected to the global network exceeded the population of the Earth and, according to forecasts, in 2025 this number would reach 70 billion.

Internet of things is a modern information system that provides transmission and processing of information at a distance, creating and using communication networks for collecting and processing information from objects and ensuring their fast and reliable work [1].

For the functioning of the information system of the Internet of things the technologies of wired and wireless networks are used.

The main disadvantage of the latter is the clear requirement for the amount of information that can be transmitted in the same frequency band. With an increase in the number of devices, there is a need to expand the frequency band, which is inefficient because of the high cost of additional bands and rigid requirements for electromagnetic compatibility, that is, there is a limitation of existing protocols that ensure the operation of wireless network technologies.

And the methods of transmitting information in the common range face the problem of distortion of the signal due to inter-channel interference.

Existing direction of elimination of these contradictions is the development of new information signals models.

II. ANALYSIS OF EXISTING PUBLICATIONS

Thus, in the works [2, 3, 4] of foreign and Ukrainian scientists, it is proposed to use polynomial spline models in the information processing task.

The main drawbacks of these models are the impossibility of unification of the methods of representation and processing of information, as well as the complexity of the algorithm for constructing high power splines.

But the usage of splines in digital systems is extremely promising, given the significantly low requirements for the hardware and software components, which in turn leads to a reduction in their cost and cost of the entire system as a whole.

Therefore, today the most interesting are new models of polynomial splines are free of deficiencies of polynomial splines. These new models include classes of trigonometric splines.

The papers [4, 7] provide general information on trigonometric splines, as well as their advantages over polynomial splines, without taking into account the peculiarities of their application to the problems of processing and restoring signals in information systems.

III. PURPOSE AND TASKS OF THE RESEARCH

From the analysis of literature it was determined that the development of information society is accompanied by an increase in the number of information devices. The main requirement is to ensure the maintenance of the information network the maximum number of different types of equipment. The main disadvantage is their joint operation, which is ensured by high-quality processing of information signals in communication channels. Therefore, the actual scientific task is to improve the methods of

978-1-7281-4184-8/19/$31.00 ©2019 IEEE

processing information in the Internet of things on the basis of fundamental trigonometric splines.

The purpose of the research presented in the article is to increase the efficiency of the information system of the Internet of things.

IV. MODELS FOR PROCESSING OF INFORMATION SIGNALS

To ensure maximum bandwidth of the channel, increase the number of channels, while narrowing the bandwidth are needed. But this leads to an increase in the duration of the signal and to the phenomenon between the channel interference, which negatively affects the reception of signals.

To solve this problem, in [5], it is proposed to use signals of Nyquist type, which have zero inter-channel influence at the moments of taking samples of the values of the sample. At the same time, the Nyquist momentum is depicted using the basic function of some class.

In this paper, we propose to use the fundamental functions of some classes, as the basic functions. One of the significant advantages of this approach is that the role of the coefficients of a generalized polynomial (or series) in these functions is the instantaneous value of the investigated signals; in turn, this makes it possible to significantly simplify the processing algorithms of such models.

A. Fundamental trigonometric splines

Let's assume that on the line $[0,T]$, given a grid $\Delta_N = \{t_i\}_{i=0}^{N}$, $0 \le t_0 \le \cdots \le t_N \le 1$ and function $f(t)$, as well as known exact values $f(t_j) = f_j$, $j = 0,1,\dots,N$ this function in the nodes of the grid Δ_N.

Let's construct a generalized polynomial

$$\Phi_N(t) = c_0\varphi_0(t) + c_1\varphi_1(t) + \cdots + c_N\varphi_N(t)$$

on the system of functions $\varphi_0(t), \varphi_1(t), \dots, \varphi_N(t)$ of a given class that depends on $N+1$- th parameters

$$c_0\varphi_0(t) + c_1\varphi_1(t) + \cdots + c_N\varphi_N(t)$$

and satisfying the conditions

$$\Phi_N(x_j) = f_i, \qquad j = 0,1,\dots,N.$$

In many cases, a system of functions $\varphi_0(t), \varphi_1(t), \dots, \varphi_N(t)$ on the grid Δ_N choose in such a way that coefficients $c_k, k = 0,1,\dots,N$, generalized interpolation polynomial $\Phi_N(x)$ were values of the interpolated function $f(t)$ in the nodes of this grid. In this case $\Phi_N(t)$ takes shape

$$\Phi_N(t) = f(t_0)\phi_0(t) + \cdots + f(t_N)\phi_N(t). \qquad (1)$$

In this case, for functions $\phi_0(t), \phi_1(t), \dots, \phi_N(t)$ conditions must be met:

$$\phi_j(t_i) = \begin{cases} 1, & j = i; \\ 0, & j \ne i. \end{cases} \qquad (2)$$

Functions for which the relation (2) takes place on the grid Δ_N are called fundamental functions of this grid whose domain definition should be less than the signal existence interval.

The representation of interpolation polynomials in the form (1) has advantages over other forms of representation, which is that there is no need to calculate the coefficients c_k, $k = 0,1,\dots,N$, interpolation polynomial. A certain disadvantage is that the change in the grid Δ_N needs to be counted $\varphi_0(t), \varphi_1(t), \dots, \varphi_N(t)$.

The fundamental systems of functions include the Shannon system, the Lagrange interpolation polynomial system, the system of fundamental interpolation polynomial splines, and the system of fundamental interpolation trigonometric polynomials.

In this case, the class of interpolation trigonometric splines attracts attention, which is more widespread and includes a class of polynomial splines. The widespread extension of these systems of functions is due to the fact that algebraic and trigonometric polynomials are linearly dense sets in the spaces of continuous and periodic continuous functions, respectively; polynomial and trigonometric splines are very convenient generalizations of these polynomials. A generalization of the system of fundamental trigonometric polynomials is a system of fundamental trigonometric splines. The functions of this system denote $ts_k(r,t)$, which depend on the parameter $r, r = 1,2,\dots$, which defines the differential properties of trigonometric splines. Moreover for any value r the fundamental trigonometric splines $s_k(r,t) \in C_{[0,2\pi]}^{r-1}$ and are represented by the formula

$$ts_k(r,t) = \frac{1}{N} + \frac{2}{N}\sum_{j=1}^{\frac{N-1}{2}} \alpha_j^{-1}(r)\left[C_j(r,x)\cos jt_k + \right.$$
$$\left. + S_j(r,t)\sin jt_k\right],$$

where

$$C_j(r,t) = \frac{\cos jt}{j^{r+1}} + \sum_{m=1}^{\infty}\left[\frac{\cos(mN+j)t}{[(mN+j)]^{r+1}} + \frac{\cos(mN-j)t}{[(mN-j)]^{r+1}}\right];$$

$$S_j(r,t) = \frac{\sin jt}{j^{r+1}} + \sum_{m=1}^{\infty}\left[\frac{\sin(mN+j)t}{[(mN+j)]^{r+1}} - \frac{\sin(mN-j)t}{[(mN-j)]^{r+1}}\right];$$

$$\alpha_j(r,x) = \frac{1}{j^{r+1}} + \sum_{m=1}^{\infty}\left[\frac{1}{[(mN+j)]^{r+1}} + \frac{1}{[(mN-j)]^{r+1}}\right]$$

For a fundamental trigonometric spline, for any r condition is fulfilled:

$$\sum_{k=0}^{N} ts_k(r,t) = 1.$$

In some cases, it is convenient to use systems of even

$$TC(r,N,t) = \{tc_j(r,t)\}_{j=1}^{N}$$

and odd

$$TS(r,N,t) = \{ts_j(r,t)\}_{j=1}^{N}$$

fundamental trigonometric splines whose differential properties are determined by the parameter r and are determined on the interval $[0,\pi]$.

Graphs of some fundamental trigonometric splines at different values of the parameter r are shown in Fig. 1 and Fig. 2. Also, from the graphs it can be seen that in the fundamental trigonometric splines, the module of maxima correspond with the distance from the interpolation node.

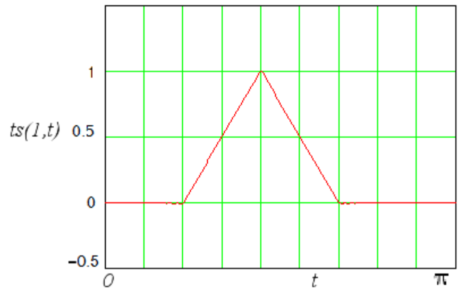

Fig. 1. A graph of the fundamental trigonometric spline on a grid $\Delta_N = \{t_j\}_{j=1}^{N}$ here $r = 1$.

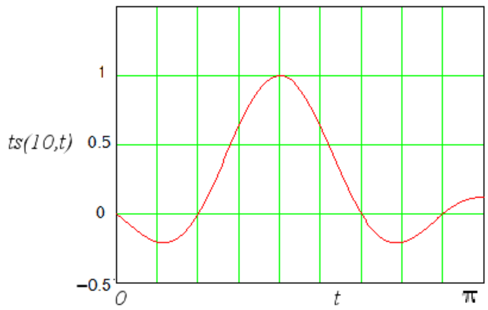

Fig. 2. A graph of the fundamental trigonometric spline on a grid $\Delta_N = \{t_j\}_{j=1}^{N}$ here $r = 1$.

Functions consisting of even and odd fundamental systems respectively on a grid $\Delta_N^{c,0}$ and $\Delta_N^{s,0}$, have a form of:

$$tc_j(r,t) == \frac{2}{N-1}\left[\frac{1}{2} + \sum_{k=1}^{N-2} c_k(r,t) cos k t_j + \right.$$
$$\left. + \frac{1}{2} c_{N-1}(r,t)\cos(N-1)\, t_j\right], \tag{3}$$

$$ts_j(r,t) = \frac{2}{N+1}\sum_{k=1}^{N} s_k(r,t) sin k t_j,$$
$$j = 1, \dots, N,$$

here

$$c_k(r,t) = [\alpha_k(r,N)]^{-1}\Phi_k^c(r,N,t),$$
$$s_k(r,t) = [\alpha_k(r,N)]^{-1}\Phi_k^s(r,N,t)$$
$$\Phi_k^c(r,N,t) = \frac{cos kt}{k^{r+1}} + \sum_{m=1}^{\infty}\left[\frac{\cos(2mN+k)t}{[(2mN+k)]^{r+1}} + \frac{\cos(2mN-k)t}{[(2mN-k)]^{r+1}}\right];$$
$$\Phi_k^s(r,N,t) = \frac{sin kt}{k^{r+1}} + \sum_{m=1}^{\infty}\left[\frac{\sin(2mN+k)t}{[(2mN+k)]^{r+1}} - \frac{\sin(2mN-k)t}{[(2mN-k)]^{r+1}}\right];$$
$$\alpha_k(r,N) = \frac{1}{k^{r+1}} + \sum_{m=1}^{\infty}\left[\frac{1}{[(2mN+k)]^{r+1}} + \frac{1}{[(2mN-k)]^{r+1}}\right].$$

Processing of information signals based on fundamental trigonometric splines

We apply fundamental trigonometric splines to construct a model that describes the transmission of a binary digital signal through a noise-canceled SDMA channel.

Let us consider the interpolation problem of the binary pulse signal *f(t)* (Fig. 3), which is formed in the transmitter.

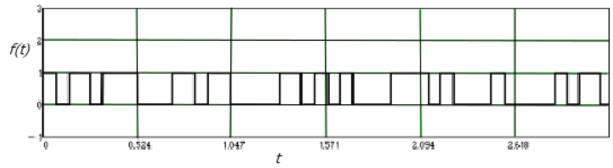

Fig. 3. Graph of pulse signal *f(t)* which enters the system of information transmission.

In the future, the signal is interpolated by the fundamental even trigonometric spline $TC_r(t)$, given by formula (3) and in the form of a continuous signal (Figure 4) enters the communication line.

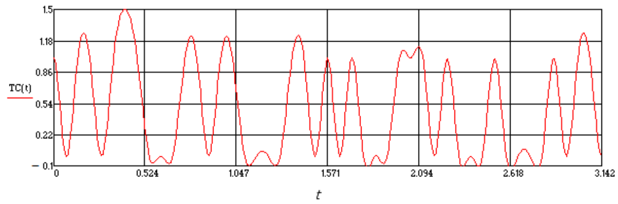

Fig. 4. A graph of a continuous signal formed by a fundamental pairwise trigonometric spline $TC_r(t)$.

The signal varies under the influence of noise when it passes through the communication channel and enters the receiver input (Fig. 5). The source of noise in the communication line could be the Gaussian noise generator.

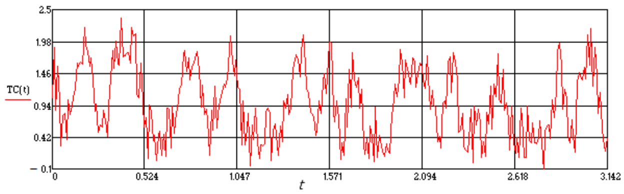

Fig. 5. Signal at the output of the communication line with noise.

The receiver then performs the filtering operation of the useful component of the incoming continuous signal using a coherent filter based on the fundamental trigonometric spline and the threshold device restores the digital signal.

As can be seen from Fig. 6, the information transmitted was restored without errors, although with some delay in time.

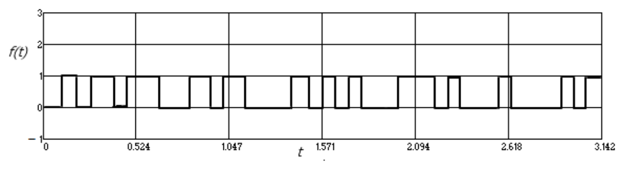

Fig. 6. Graph of the restored $f(t)$ of the information signal.

B. *Results of research*

To verify the functioning of the information system for the processing and transmission of digital signals based on fundamental trigonometric splines N bit of information was transmitted with a constant rate. The noise power was changed and the probability of $P_{mis.}$, was determined, indicating the impedance of the information system.

The graphs $P_{mis.} = f(\frac{E_6}{N_0})$ of dependence on the estimation of the probability of error from the power of the noise source (Fig. 7), for information processing systems based on the fundamental trigonometric spline and the similar on the basis of the Hermite spline [5] was created

By the criterion according to which the noise immunity is evaluated by the required ratio of average signal strength and interference at the input of the receiving device (signal/noise ratio)

$$P_{mis.} = q^2 = \frac{E_6}{N_0}$$

and is determined by the fact that the smaller the value q^2, the higher the noise immunity of the information transmission system, that is, the probability of receiving a useful signal

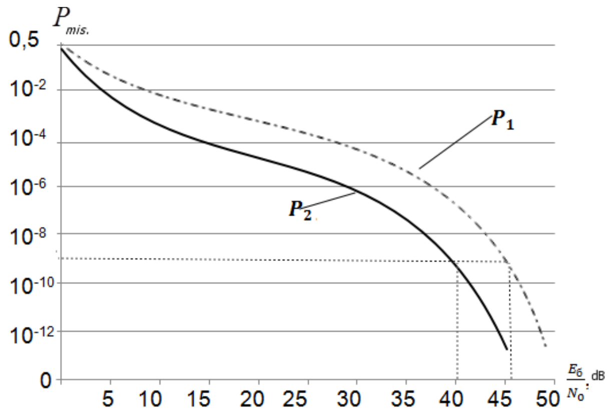

Fig. 7. Graphs of the dependence of the error probability estimate on the power of the source of noise for P_2 is system with the Hermit splines, P_1 is system with fundamental trigonometric splines.

According to this criterion, the noise immunity of the information transfer system implies that with an optimum value of the probability of error 10^{-9}) for the system based on the Hermite splines, the value of the signal / noise ratio $q_2^2 = 40$ dB, but for a system based on fundamental trigonometric splines $q_1^2 = 46$ dB.

On the basis of the performed calculations, it follows that the system noise immunity has been raised by 6%.

V. Conclusion

On the basis of the analysis of the methods of information processing in wireless networks, which provide the connection of a large number of devices into one Internet information network, the problem of simultaneous transmission of information in the common band without the expansion of the frequency band is revealed. In these channels, there is a signal distortion due to the interference of the neighboring signals, which can manifest themselves as noise. In modern works, to weaken this phenomenon, methods based on polynomial splines are used that have a number of shortcomings. The classes of fundamental trigonometric splines are free from the disadvantages of polynomial splines.

To construct these functions there is no need to solve any system of equations, and algorithms for constructing trigonometric splines do not depend on the power of these splines, contrary to polynomial splines. Application of these models in the methods of information processing will increase the performance of the Internet of things information network.

Prospective ways for further research in this direction would be the range of issues regarding the development of new and improvement of existing methodology of information processing on the Internet of Things for further use in Smart Home, Smart Enterprise or Smart City technologies

References

[1] R. Want, N. Bill, and S.Jensonю “Enabling the internet of things,” Computer, Jan. 2015.

[2] D. Singh, M. Singh, and Z. Hakimjon. “Signal Processing Applications Using Multidimensional Polynomial Splines,” *Springer Singapore*, Dec. 2019.

[3] A.Z. Averbuch, P. Neittaanmaki and V.A. Zheludev. “Spline and spline wavelet methods with applications to signal and image processing”, *Springer*, Jun. 2015.

[4] V.P. Denysyuk. “Fundamentalni funkciyi ta trygonometrychni splajny [Fundamental functions and trigonometric splines], ” Kyiv, Ukraine: Vipol, 2015. (In Ukrainian).

[5] I.F Bojko, M.G. Gordyeyev and A.I. Kutin. “Peredavannya i pryjmannya cyfrovyx sygnaliv u splajnovyx bazysax [Transmission and reception of digital signals in spline bases].” *Elektronika ta systemy upravlinnya*, no.3 (33), pp.5-12, 2012. (In Ukrainian).

[6] I.V. Panchenko, O.I. Voskolovych, I.O. Churilov and D.G. Koltovskov. “Model` rozraxunku jmovirnosti bitovoyi pomylky v systemax nyz`koshvydkisnoyi peredachi danyx LORA [Model of calculation of bit error probability in LORA low-speed data transmission systems].” *Zbirnyk naukovyx pracz` Vijs`kovogo instytutu telekomunikacij ta informatyzaciyi*, no.1, pp.73-76, 2018. (In Ukrainian).

[7] V.P. Denysiuk, and O.V. Negodenko. “Mathematical models on the basis of fundamental trigonometric splines,” *Science and Education a New Dimension. Natural and Technical Sciences*, Feb. 2018, pp. 14–18.