Introduction of Fog Computations to Measuring System Collection and Accounting of Data of Distributed Internet of Things

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Abstract. The article deals with the problems of speed and timeliness of the development of control actions from digital management systems. Generalization of researches is given. The role of mathematical applications of game theory for the role in the implementation of fog and boundary computations in the paradigm of the development of digital signal processing systems as well as their optimization value are substantiated. A particular generalization is developed and is given from the processing of an encoded signal sequence that demonstrates the operation of a humidity sensor from the viewpoint of bringing it to the basis of an antagonistic game in order to determine the optimal strategy of the device's behaviour at a given time interval. The practical significance of the study is confirmed by a new approach to the implementation of economic methods for analysis of probabilistic outcomes within the framework of game theory in an algorithm for analysis of a digital signal for a linear comparator of recorded physical quantities in the form of digital levels. The value of such analysis metrics in network-centric distributed systems of the Internet of things in multiplexing environments is given.

1. Rationale
The synthesis of complex technical systems and control systems is associated with a number of problems associated with the speed of processing and the development of control actions (building the necessary response policy). Demarcation of descriptors of future processes and events in a closed system is of the great importance even at the stage of primary registration of input data, i.e., the interoceptive process of minimization of information entropy about the parameters of active work monitoring and determining the state of the physical environment.

The possibilities of integrating fog computing into the process of digital signal processing of incoming signal parameters in a discrete real-time system responsible for collecting and accounting (dispatching) data will be studied in this study. The relevance of the studied topic is confirmed by the
need to take into account the data taking into account the outlined trends in the development of implementations of tunneling and edge computing, as well as in the invariant multi-scenario execution of the developed algorithms using the implementation of methods from game theory and predicates of artificial intelligence in digital signal processing.

The aim of the study is to develop an algorithm for multiplexing information processing in the hardware and software complex of a SCADA system for the industrial Internet of things based on the theory of static solutions.

As part of the generalization of the results of this study, works devoted to theoretical [1], [2], [3] and applied aspects [4], [5], as well as an analysis of existing means of providing technologies for the physical layer of information transfer in Ethernet networks [6], [7] have been studied.

The scientific significance of the study is confirmed by an innovative approach to the use of economic methods of mathematical content in an algorithm for a linear comparator of registered physical quantities in the form of digital levels encoded in a five-level PAM code (2B1Q) or similar coding systems compatible with IEEE 802.3/802.15.

The need to use the apparatus of linear operators for logical signal levels at the stage of primary processing in multiplexing environments is caused by the requirements for optimization purposes in timing media for information transmission. In these media there are determinants of time and the number of information units transmitted per unit of time [8].

In its’ turn, it is very important in perspective low-power networks and information transmission systems (LoRaWAN, LPWAN, Zigbee).

In this study, the use of a particular case of fog computing will be considered using the example of formalizing the processing of the vector of values of the potential code 2B1Q that signalling the results of reading several sensors of relative humidity with a stable measuring nature in the range of -2.5 V to 2.5 V (Fig. 1).

**Figure 1.** Timing diagram of the potential 2B1Q code for a digital sensor.

The accuracy class of capacitive sensors used in integrated automation and IoT systems for modern generations of SCADA systems is ± 2% relative humidity in the range from 5 to 95% with a two-point calibration. It shall be borne in mind that capacitive sensors have limitations on the working distance, the sensitive element can be located far from the signal amplification circuit in order to avoid parasitic effects of the connecting cable (the level of fluctuations in the sensor capacitance is not large) [9].

In this study, the end result of the fog computing shall be the determination of the final solution for selection of the optimal strategy for the subsequent calibration of the strobe during the device setup process. Taking into account the complex nature of the behavioural function of a number of sensors and actuators, it is advisable to use such monitoring on a regular basis, thereby providing adaptive control.

The complex nature of the behaviour of sensors underlies their design and fundamental features: one way or another, transient processes and not always correct response time, unpredictable failure time, cause great concern of the control systems operators.
SCADA systems cannot find inconsistencies in the operation of peripheral devices, since they work directly with already processed data, and direct access to data streams is difficult. In this regard, it was decided to work with data "at the output" with a sensor, i.e., directly implement predictive analytics.

Predictive analytics uses statistical methods, data mining methods, game theory, analyzes current and historical facts to make predictions about future events [10]. In particular, predictive analytics helps to determine the optimal strategy for the operation of devices that can use the joint nature of the useful action (measurements), and to determine the specific paradigm of optimal operation in mixed modes of operation (for example, with parallel connection, which greatly simplifies the solution of this computational problem through fog computing (i.e., computations taking place in the information transmission path from the end device to the control system) [11] [12].

In order to do this, it is necessary to present the values of the current signal values in the MLT3/2B1Q code already at the level of the primary converter with its reduction to the basis of the matrix equation. This will allow the analysis of the game (sample of the device operation) to be done through the apparatus of game theory and vector mathematics that is easily calculated in arithmetic and logic unit.

Let us analyze the operation of the signal levels for a control sample of 9 values (where 0 is -2.5V, and 9 is 2.5V), given by the payoff matrix $A$. Let us find a solution through calculation.

$$A = \begin{pmatrix} 7 & 6 & 3 \\ 5 & 6 & 9 \\ 8 & 4 & 7 \end{pmatrix}$$

Let us find the lower and upper game prices for the inputs of the digital multiplexer (which perceives the input values and weights of the physical values of the sensors $\alpha$ and $\beta$, where weight of $\alpha$ is 5; weight of $\beta$ is 6). Since $\alpha \neq \beta$, there is no solution in pure strategies. A solution is found in mixed strategies: $X(x_1, x_2, x_3), Y(y_1, y_2, y_3)$, where $\sum x_i = 1$ and $\sum y_j = 1$ [13].

Suppose $V$ is the game value. It shall be denoted as

$$U_i = \frac{x_i}{V}, \quad Z_j = \frac{y_j}{V}.$$ Let us compose two mutually dual tasks for the sensor (1):

$$\begin{align*}
7u_1 + 6u_2 + 3u_3 &\geq 1 \\
5u_1 + 6u_2 + 9u_3 &\geq 1 \\
8u_1 + 4u_2 + 7u_3 &\geq 1 \\
F &= u_1 + u_2 + u_3 = \frac{1}{V}
\end{align*}$$

$$\begin{align*}
7z_1 + 6z_2 + 3z_3 &\leq 1 \\
5z_1 + 6z_2 + 9z_3 &\leq 1 \\
8z_1 + 4z_2 + 7z_3 &\leq 1 \\
G &= z_1 + z_2 + z_3 = \frac{1}{V}
\end{align*}$$

The dual problem is solved using the simplex method for the sensor. Additional non-negative variables $z_4, z_5, z_6$ are introduced and linear programming problem in is obtained in the standard form (2):

$$\begin{align*}
7z_1 + 6z_2 + 3z_3 + z_4 &= 1 \\
5z_1 + 6z_2 + 9z_3 + z_5 &= 1 \\
8z_1 + 4z_2 + 7z_3 + z_6 &= 1 \\
z_i &\geq 0, \quad i = 1, 6 \\
G &= z_1 + z_2 + z_3 \rightarrow \max
\end{align*}$$

Vectors of the coefficients for the unknowns and the vector of free terms are given (3):
The solution is executed in the form of simplex tables (table 1).
As the primary basis, vectors $P_4$, $P_5$, $P_6$ are taken. These vectors form the identity matrix.

As a result, the following solution is obtained (4):

$$Z_{B3} = \left(\frac{1}{15}, \frac{7}{90}, \frac{1}{45}, 0, 0, 0\right); \ G_{B3} = \frac{1}{6},$$

(4)

This solution of optimal since $G$-line has no negative elements. Thus, solution of dual problem for sensor is as follows:

$$z_1 = \frac{1}{15}; \ z_2 = \frac{7}{90}; \ z_3 = \frac{1}{45}; \ G_{\text{max}} = \frac{1}{6},$$

(5)

Table 1. Simplex table for solution.

| $CT_0$ | $B_0$ | C | $P_0$ | 1 | 1 | 1 | 1 | 0 | 0 | 0 | Q |
|--------|-------|---|-------|---|---|---|---|---|---|---|---|
|        |       |   | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ | $P_6$ |
| P_4 | 0 | 1 | 7 | 6 | 3 | 1 | 0 | 0 | 0 | 1/7 |
| P_3 | 0 | 1 | 5 | 6 | 9 | 0 | 1 | 0 | 0 | 1/5 |
| $\leftarrow P_6$ | 0 | 1 | 8 | 4 | 7 | 0 | 0 | 0 | 1 | 1/8 |
| $G$-stroke | 0 | -1 | -1 | -1 | 0 | 0 | 0 | 0 |

| $CT_1$ | $B_1$ | $\leftarrow P_4$ | 0 | 1/8 | 0 | 5/2 | -25/8 | 1 | 0 | -7/8 | 1/20 |
|--------|-------|------------------|---|-----|----|------|-------|---|---|------|------|
| P_3 | 0 | 3/8 | 0 | 7/2 | 37/8 | 0 | 1 | -5/8 | 3/28 |
| $\rightarrow P_1$ | 1 | 1/8 | 1 | 1/2 | 7/8 | 0 | 0 | 1/8 | 1/4 |
| $G$-stroke | 1/8 | 0 | -1/2 | -1/8 | 0 | 0 | 0 | 1/8 |

| $CT_2$ | $B_2$ | $\leftarrow P_5$ | 0 | 1/5 | 0 | 0 | 9 | -7/5 | 1 | 3/5 | 1/45 |
|--------|-------|------------------|---|-----|----|---|---|-------|---|----|------|
| P_1 | 1 | 1/10 | 1 | 0 | 3/2 | -1/5 | 0 | 3/10 | 1/15 |
| $G$-stroke | 3/20 | 0 | 0 | -3/4 | 1/5 | 0 | -1/20 |

| $CT_3$ | $B_3$ | P_2 | 1 | 7/90 | 0 | 1 | 0 | 37/180 | 5/36 | -4/15 |
|--------|-------|-----|---|-----|---|---|-------|------|------|
| $\rightarrow P_3$ | 1 | 1/45 | 0 | 0 | 1 | -7/45 | 1/9 | 1/15 |
| P_1 | 1 | 1/15 | 1 | 0 | 0 | 1/30 | -1/6 | 1/5 |
| $G$-stroke | 1/6 | 0 | 0 | 0 | 1/12 | 1/12 | 0 |

The solution for the direct problem is written down from the simplex table $ST_3$: $U_{\text{opt}} = \left(\frac{1}{12}, \frac{1}{12}, 0, 0, 0, 0\right).$ Thus, $u_1 = \frac{1}{12}; \ u_2 = \frac{1}{12}; \ u_3 = 0; \ F_{\text{min}} = G_{\text{max}} = \frac{1}{6} = \frac{V}{V}$.

From here the game value of $V = 6$ is found; mixed strategies of the first player (samples $x_1$) and mixed strategies of the second player (samples $y_1$): $x_1 = 1/12; \ y_1 = 1/15; x_2 = 1/12; \ y_2 = 7/90; x_3 = 0; \ y_3 = 1/45; \ x_3 = 2/15; \ y_3 = 7/90; \ x_2 = 1/2; \ y_2 = 7/90; \ x_1 = 1/2; \ y_1 = 2/15.$

The use of the minimax principle in discrete systems within the framework of the fog computing paradigm makes it possible to develop specific solutions even at the stage of information transfer to the
processing environment, taking into account the reduction to the vector form of the values necessary for processing [14] [15].

The practical importance of use of the basis of antagonistic games in digital signal processing at the stage of their multiplexing is great: it also allows to use the predictive analytics based on the excitability scales. It characterizes most of the known neural and recurrent analytics systems [16].

The approximated values of the game value results and mixed strategies make it possible to develop recommendations for accounting of work in complex systems, defining new opportunities for SCADA systems (Fig. 2) in terms of prediction of conflict situations, failures, optimal work scenarios, and work cycles [17].

Using the analyzed example, it can be concluded that the implementation of such a tunnel computation in the information exchange path makes it possible to provide the most complete information about the behaviour of the signal for the analysis system, taking into account that this is mentioned in advance and provided in the form of a matrix of values (in the example there are 9 signal levels, and coding itself in the final form is reduced to only five levels).

![Figure 2. Architecture of a distributed SCADA system.](image)

The linear nature of the calculations (determination of the lower and upper sums of the "payoff") for conflict situations requires a more detailed study and analysis in the optimization calculations of the algorithm, finding the optimal path for iterative computation of mixed work strategies.

2. Findings
In this study a generalization of a particular case from game theory is for the first time applied within the framework of organization of a fog computing algorithm for digital signal processing from digital humidity sensors of a SCADA system with parallel connection in order to determine optimal strategies for working in a predictive basis. The prospects and practical significance of the implementation of the mathematical apparatus in optimizing the process of measuring data from the IoT end devices in the network-centric paradigm are presented [18].
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