Development of automatic control system of satellite signal parameters with TDMA technology

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Abstract. The control of the frequency spectrum state under operating conditions of the satellite networks that include plenty of satellite earth stations is one of the main functions of ground segment of space communication systems. In this case, the control system of the satellite network must measure the parameters of separate network segments or separate earth station if it is necessary. The necessity for selective measurements is relevant in the following cases: the power level, noise level or spurious radiation level of any earth station is significantly higher than the nominal one. The overview of some existing monitoring systems that makes automatic control of the frequency spectrum is presented. The analysis of the problem arisen during the functioning of satellite TDMA networks that involve plenty of earth stations is presented. Based on the analysis, it was concluded that the existing control systems of the satellite networks do not allow measuring high frequency parameters of separate earth stations under TDMA technology. The analysis of the problem of measuring the channels parameters of satellite network functioned by using the TDMA technology is presented. The differences between computations of channel power under “single channel per carrier“ technology and the TDMA technology are presented. The authors proposed an automatic control system of high-frequency (HF) parameters of satellite signals, functioning by using the time-division multiple access technology. The block diagram of this system and description of its operation are presented. The conditions for implementing this automatic control system are defined. The time chart and its characteristics were calculated during measurements executing by this automatic control system. The method of match making between the received signals through the satellite segment and the identifiers of earth stations of the satellite network is presented.

1. Introduction

Satellite telecommunication networks include plenty of communication channels functioning by satellite transponders and satellite earth stations. Faults that happen during the satellite earth station exploiting are the reason of separate segments malfunction of satellite networks. In this case the necessity for fast revealing of emergency satellite earth station arises that creates spurious radiations.

Thereby, linear operating of satellite earth station is a necessary condition for a satellite network functioning [1], [13], [15]. Topicality of this problem is described in the suitable prescription of the International Telecommunication Union [2].
Existing method for revealing location of radiation source by geolocation system in case of TDMA satellite network is not always applicable. The reason for this includes restrictions connected with satellites’ positions used in this method [3].

The time division multiple access (TDMA) is one of the technologies that include plenty of satellite earth stations [4]. Development of control system of satellite signals’ parameters of satellite earth stations by use of the TDMA technology is the relevant task.

2. Existing satellite signals monitoring system review
Measurement systems of satellite signal parameters constitute a part of satellite monitoring systems. The review is composed by using the reports of the following enterprises: Monics Enterprise [5], [6]; Thales Alenia Space [7].

Reviewed above monitoring systems ensure required control level of frequency spectrum of spacecraft payload traffic. However, interference identification of earth station whose antenna is precisely directed at the satellite under TDMA satellite network impossible by using the reviewed systems.

3. Problem formulation
The analysis is executed as an example of signal power control. Let us consider a channel functioning by using “single channel per carrier” technology. Signal power $P$ for the channel can be expressed as:

$$P = \frac{V_{RMS}^2}{R},$$

where $V_{RMS}$ = root-mean-square voltage; $R$ = reference resistance.

The root-mean-square voltage $V_{RMS}$ can be expressed as:

$$V_{RMS} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} V_i^2},$$

where $N$ = number of samples allocated to the pixel concerned; $V_i$ = samples of envelope; [8].

Signal spectrum is calculated by means of the fast Fourier transform (FFT) algorithm. Initial data for the FFT algorithm are discrete Fourier transform (DFT) complex values $X(k)$ that are calculated as:

$$X(k) = \sum_{n=1}^{N-1} x(nT) e^{-\frac{2\pi i nk}{N}},$$

where $N$= number of samples used for calculation of FFT; $k$ = harmonic number, $k= 0, 1, \ldots N-1; n$ = number of sample; $T$ = sampling interval [9].

For a satellite communication channel functioning by TDMA technology power calculation for one channel by (1) formula within selected frequency range has a random value. For power measurement of satellite networks’ return carrier channel functioned by TDMA technology it is necessary to conduct a time gating. Nominal power for a channel by using the TDMA technology thus may be calculated by the (1) formula within time period restricted by the time-slot for the channel.

4. Automatic control system of satellite signals’ parameters under TDMA technology
This system includes the following functional blocks: digital stream analyzer, TDMA controller, workstation of TDMA monitoring station, spectrum analyzer, and switch. After aggregation this system into the main monitoring system it can be titled as TDMA monitoring system.

TDMA control system allows executing measurements in satellite network with time-division multiplex of separately selected satellite earth station in real-time operation mode. TDMA satellite earth station is synchronized with TDMA network; it executes measurements of signal spectrum in real-time operation mode. Workstation of TDMA satellite earth station receives and processes data derived from digital stream analyzer through the earth channel. Workstation of TDMA satellite earth station ensures synchronization of monitoring system with TDMA network and transmitting the time gating pulse into specific spectrum analyzer destined for TDMA signals measurement. In as much as it requires control
of high bit-rate fast signals switching, the functions of control by using measurements in real-time operation mode are implemented by using separate TDMA controller. TDMA controller derives the information from workstation of TDMA satellite earth station about time-slots sampling of appointed satellite earth station for precise start and end positions choice of measurements time. The TDMA controller sends measurement control signals to the input of a specialized spectrum analyzer and the required data are measured. Thus, spectrum analysis with time gating is performed [10]. Measurement results are saved and processed in equipment of head monitoring station. Using the separate TDMA controller for control in real-time operation mode reduces significantly the requirements for processor performance of TDMA satellite earth station’s workstation.

Block-diagram of automatic control system of satellite signals’ parameters under TDMA is described below.

5. Conditions of system implementation execution

5.1. Time gating of measurements
TDMA signal spectrum measurement from satellite earth station in real-time operation mode is possible under certain condition:

\[ T_{d.g.c.} + T_{\text{trig}} + T_{\text{mea}} < T_{d.s.c.}, \] (4)

where \( T_{d.g.c.} \) – delay time of signal in ground communication channel; \( T_{\text{trig}} \) – setup time of measurement delay (delay trigger time); \( T_{\text{mea}} \) – capture time from spectrum analyzer; \( T_{d.s.c.} \) – delay time of satellite channel.

Figure 2 shows time diagram that depicts condition according to the (4) expression:

a) sequence of active signal’s transmitting time of satellite earth station (outburst);
b) sequence of signals arrived to TDMA SM workstation through the satellite downlink;
c) sequence of automatic measurements executed by TDMA subsystem.

Figure 1. Block diagram of an automatic control system of satellite signal parameters with TDMA technology.
5.2. Delay time calculation in earth communication channel

Delay time equal to signaling delay from satellite control centre (SCC) workstation to TDMA SM workstation is equal:

\[ T_{d,e.c.} = T_{d,1} + 2T_{d,2} + 2T_{d,3} \]  \hspace{1cm} (5)

where \( T_{d,1} \) = signaling delay in fiber optic cable; \( T_{d,2} \) = serializing delay; \( T_{d,3} \) = router delay.

5.2.1. \( T_{d,1} \) calculation:

\[ T_{d,1} = \frac{L}{V_{gr}} \]  \hspace{1cm} (6)

where \( L \) = length of fiber optic line; \( V_{gr} \) = group velocity of electromagnetic wave.

\[ V_{gr} = \frac{c}{N(\lambda)} \] \hspace{1cm} (7)

where \( c \) = speed of light; \( N(\lambda) \) = effective group refractive index per one nm.

For the fiber of Lucent TrueWave®RS (G.655) company \( N(\lambda) \) is equal to 1.470.

Under \( L = 1000 \) km, \( V_{gr} \) is equal:

\[ V_{gr} = \frac{3 \times 10^8 \text{ m/c}}{1.470} = 2.0408 \times 10^8 \text{ m/s}; \]

\[ T_{d,1} = \frac{L}{V_{gr}} = \frac{10^6 \text{ m}}{2.0408 \times 10^8 \text{ m/c}} = 0.49 \times 10^{-2} = 49 \text{ ms}. \]

5.2.2. \( T_{d,2} \) calculation:

\[ T_{d,2} = \frac{N(k)}{IR\,(\text{int})}; \] \hspace{1cm} (8)

where \( N(k) \) = size of transport stream packet, bit.

Initial conditions of calculation:

- MPEG-TS transport stream packet is 204 byte;
- Digital data link channel E1 is 2048 kbps.

Then \( T_{d,2} = \frac{N(k)}{IR\,(\text{int})} = \frac{204 \times 8 \text{ bit}}{2048000 \text{ bps}} = 0.7 \text{ ms}. \)

5.2.3 \( T_{d,3} \) calculation. Router delay value caused by a router may be estimated driven by prescription ICU-T G.1050 (11/2005) [11]. Table 1 shows delay time values in information receiving depending on router role.

| Role                  | Total average delay | Delay fluctuation |
|-----------------------|---------------------|-------------------|
| Access gateway        | 10 ms               | 16 ms             |
| Internetwork gateway  | 3 ms                | 3 ms              |
| Distribution          | 3 ms                | 3 ms              |
| RAM                   | 3 ms                | 3 ms              |

Thereby, delay time \( T_{d,3} \) in expression (3) is equal to:

\[ T_{d,3} = T_{a,e} + T_{i,e} + T_{dsb} + T_{c} \] \hspace{1cm} (9)
where $T_{d.g} =$ delay time in access gateway; $T_{d.i.g.} =$ delay time in internetwork gateway; $T_c$ is allocation delay time; $T_{dsb}$ is delay time in mainstore memory.  

$$T_{d.3} = 10\,\text{ms} + 3\,\text{ms} + 3\,\text{ms} + 3\,\text{ms} = 18\,\text{ms}.$$  

$T_{d.1}, 2T_{d.2}, 2T_{d.3}$ values are put in expression (5):  

$$T_{d.g.c.} = 4.9\,\text{ms} + 2 \times 0.7\,\text{ms} + 2 \times 18\,\text{ms} = 42.3\,\text{ms}.$$  

5.3. Calculation of signal passage delay time through the satellite channel.  
Initial condition of calculation:  
- Inclined distance from satellite earth station to spacecraft: $l = 36000$ km;  
- EMR Spreading velocity $\nu = 3 \times 10^8\,\text{m/s}$.  

$$T_{d.s.c.} = \frac{2l}{\nu} = \frac{2 \times 36000 \times 10^3}{3 \times 10^8} = 24 \times 10^{-2}\,\text{s} = 240\,\text{ms}.$$  

5.4. Readiness assessment of spectrum measurement execution.  
Initial data of numerical properties of readiness for spectrum measurement execution by measuring equipment has the following properties:  
- real-time spectrum analyzers ensure spectrum capture time not more than ten microseconds i.e. less than 0.1% of delay time in earth communication channel [12];  
- delay time of measurement setup may be installed on minimal values up to 0 seconds.  

In this case $T_{\text{trg}}$ and $T_{\text{mea}}$ values negligibly small and expression (4) may be performed in the following view:  

$$T_{d.g.c.} < T_{d.s.c.} \quad (10)$$  

According to above-mentioned calculations $T_{d.g.c.}= 42.3\,\text{ms}$; $T_{d.s.c.}=240\,\text{ms}$ i.e. equation (10) is right and the condition of implementation is executed. This condition allows executing measurements of signals’ HF-parameters in real-time operation mode.  

6. Control method  
Based on the above-mentioned diagrams the following operations are executed:  
- single measurement of satellite earth station time-slot and signal spectrum express analysis execution;  
- measurement series execution under several time-slots and expanded signal analysis execution;  
- matching setup of received signal to ID numbers of satellite earth station.  

Express analysis is executed on measurement basis that is executed in real-time operation mode and accepted calculated data about signal delay in earth and satellite segments. Matching between a signal accepted through the satellite segment and an ID number of satellite earth station is executed on the basis of the information from data base of satellite network.  

Expanded analysis is executed in case of express analysis execution based on the calculated data about signal delay is impossible. Expanded analysis execution is presented below.  

Matching between a signal accepted through the satellite segment and an ID number of satellite earth station is executed by using the correlation analysis. $X, Y$ quantitative attribute system is accepted as an analysis object when after n independent measurements are deduced number couples: $(X_1, Y_1), (X_2, Y_2), \ldots (X_n, Y_n)$.  

$X$ quantitative attribute includes plenty of numbers $(X_1, X_2 \ldots X_n)$ and $Y$ quantitative attribute includes plenty of numbers $(Y_1, Y_2, \ldots Y_n)$.  

In the case under consideration, numbers of $X$ multitude are intervals $x_i$ between time markers of time-slots’ start of satellite earth station that accepted through the earth communication channel; number of $Y$ multitude are intervals $y_i$ between front edges of HF signals accepted through the satellite communication channel.
Representativeness of $n$ samples amount of $X_i, Y_i$ values for analysis execution is assessed by delay time of signal reception of satellite channel regarding signal accepted through the earth communication channel.

Value of assessment of $r$ correlation coefficient can be expressed as:

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \sum_{i=1}^{n} (y_i - \bar{y})^2}}, \quad (11)$$

where $\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$; $\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i$; $n = $ amount of samples, [14].

The value of $r$ correlation coefficient is calculated for each spectrum measurement series within satellite link delay time $T_{d.s.c.}$. Matching between signals accepted through the earth communication channel and satellite link is installed for measurement series with the largest value of correlation coefficient.

7. Conclusion

The paper contains functional pattern of automatic control system of HF-parameters measurements of satellite signals’ data transmission and communication by using the TDMA technology.

The above-mentioned calculations confirm implementation opportunity of this system with the aim for service quality improving of satellite networks.

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