An Approach to Data Transmission Process Modelling in Automated Power Accounting Systems

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Abstract. An accurate accounting of electricity consumption is a relevant task for the improvement of energy efficiency both in industry and in housing and communal services. An important step in solving this task is the deployment of automated metering systems that allow obtaining analytical information required for development and adjustment of energy saving programs. The development of data transmission technologies over cellular networks has led to the widespread use of wireless channels for information exchange in automated energy control and monitoring systems. As both main and reserve communication channels, these systems can use technologies with channel switching (GSM CSD) and packet switching (GPRS). The choice of a particular data transmission technology in this case depends on a number of technical or economic factors. The aim of this work is the development of a conceptual model of the data transmission process in the automated energy consumption monitoring systems with direct connection of meters via GSM CSD and GPRS channels. For modeling the physical layer of the radio channel the model of signal propagation of Okamura-Hata was chosen. Calculation of call blocking probability is based on Erlang-B model. MIR C-01 and CET-4TM have been chosen as electric energy meters. In the work, the conceptual model of data transmission process in the monitoring system with GSM CSD and GPRS channels is offered, being a basis for its further mathematical formalization for the purpose of modelling of an information exchange between elements of the automated energy consumption monitoring system.

Keywords. Automated Power Accounting System, conceptual model, GSM, Okamura-Hata model, Erlanga-B model

1. Introduction

Currently, the development of information and network technologies makes it possible to organize an automated exchange of information between nodes of complex accounting systems located at great distances from one another. An example is distributed automated power accounting systems (APAS), controlled units of which can be located hundreds of kilometers away from the data collection center. For information transfer in such systems, cellular communication channels aimed at digital data transmission can be used.

In this paper, APAS is viewed as a multilevel hierarchical data measurement system that collects, processes and stores the results of measured values of control parameters in a universal time system, as well as conducts diagnostics of hardware and software that constitute the system.

The task of modeling information exchange in the automated systems for collecting and processing information is an urgent one since at the stages of development of such systems it is possible to test
design solutions without the need for expensive field tests. The practice of application of the theory and analytical and simulation modeling tools proves to be effective and relevant in the analysis of data transmission processes in automated control systems for radar stations [1], rolling stocks at railway stations [2], technological processes in housing and utility sector [3] and gas transportation sector [4-6], as well as in facilities for power accounting [7] and monitoring of process equipment in the gas industry [8].

In this paper, the task is to develop a conceptual model of data transmission process over the channels of a cellular network in APAS with direct connection of meters. The process of information exchange between the server side and data measuring devices is implemented via wireless GSM cellular communication networks, with the use of CSD channel switching and GPRS packet switching. The choice of these technologies is attributable to the fact that the monitored objects may be located in remote areas that often lack radio communication of up-to-date standards.

Modeling of the GSM CSD/GPRS radio interface is implemented at two layers: the physical layer is accountable for radio propagation of cellular network signals, while the data-link layer provides access to radio channel resources. In order to select and justify the use of physical and data-link layer models, an analysis of existing solutions published in available sources was conducted as part of the task.

Complete properties of radio propagation can be obtained by solving Maxwell's equations under certain conditions, corresponding to the physical properties of objects that create obstacles to the propagation. However, the complexity and variety of operating conditions for radio channels often make it difficult to build an accurate deterministic model. In these cases, empirical (statistical) models are commonly used. These models are designed to estimate path loss in order to predict attenuation in typical working environments, for example, in urban and suburban areas. Such models are based primarily on empirical data, taking into account the frequency range and geographical area.

In accordance with ITU-R 1546-4 recommendations, the Okumura-Hata model is expected to be used to calculate the signal attenuation at ultra-high frequencies. A comparative analysis of statistical models of cellular transmission channels, including the results of empirical ones - Okumura model [9], and their analytical formulation - Hata model [10], is given in papers [11-16]. The Okumura-Hata model is the most common model for predicting signal attenuation in urban environments, with link distances of more than 1 km between transmitting and receiving antennas. It should be noted that it is not applicable for accurate calculation of radio signal propagation properties in LTE and 5G networks [12]. However, for earlier cellular standards, the use of this model is justifiable. Therefore, the Okumura-Hata statistical model remains in demand today when analyzing the properties of wireless radio signal propagation. Thus, in the work [17] the authors use this model for estimating the field level attenuation in cities with specific architecture and areas with complex topography [16], developing simplified methods of calculating path loss [18], and improving the model for calculating the energy characteristics of mobile radio channels under the influence of railway infrastructure [15]. The use of the Okumura-Hata model is not limited to cellular networks, but also extends to digital television systems on VHF/UHF frequencies, according to the recommendations of ITU-R 1546-3 [19].

Thus, the Okumura-Hata model was chosen for modeling the physical layer of the radio channel, namely radio signal attenuation in a GSM cellular network.

One of the main characteristics that determine the quality of operation of the radio interface at the data-link layer is the probability of blocking (denying) access to network resources. Evaluation and analysis of this important characteristic of the cellular network operation are also given considerable attention among researchers [20-26].

The most rapid development is currently taking place in so-called multiservice models designed to calculate blocking in networks with heterogeneous traffic [24-26]. However, within the framework of this task it is unnecessary since it deals with the radio channel, where the main part of the traffic is generated exclusively by the interrogated devices - electric power meters. In the work [20] the analytical model of the data transmission process via the GPRS channel in the form of a multi-server queueing system is proposed and the blocking probability related to the rate of incoming requests is analyzed. As shown in the work [21], the Erlang B formula for the blocking probability can be applied
at the network design stage. However, a comparative analysis of the modeling results and statistical data provided by the cellular operator shows a slight difference (up to 10%) between the calculated and empirical data. Therefore, the Erlang B model was chosen for modeling APAS access blocking to GPRS radio interface resources.

2. The structure of APAS

There are various options for structural implementation of APAS [27]. In this paper the system with direct connection of electricity meters is examined, the block diagram of which is shown in Figure 1. The system in question consists of two layers:

− a set of metering points, each of which is represented by an electricity meter (EM), grouped within one power facility and connected to one data reception and transmission device;
− information-computing complex (ICC), which interrogates EMs over communication channels and stores the data obtained.

Direct connection of meters to the ICC is recommended for systems with a small number of power facilities and meters with reliable communication channels and no need for real-time (3 to 5 minutes) monitoring of power consumption.

![Figure 1. Automated metering system structure with direct connection of EM](image)

Each power facility may contain any number of SET-4TM and MIR C-01 electricity meters that are connected to channel forming device (CFD) via an interface converter (IC). IC is a transparent device that does not cause an additional delay in signal propagation. Interrogation of metering points is carried out via GSM cellular network with the use of either CSD channel switching or GPRS packet switching. Channels using the same technology are interrogated sequentially; if there are channels using both technologies, interrogation of metering points is done simultaneously. Channel reservation is not provided.

In the process of designing such a system, the mean time spent interrogating one EM, as well as the mean time spent interrogating a group of EMs for each power facility, should be defined in accordance with a communication channel. Based on the values of these parameters, it is possible to find the number of EMs that can be integrated into one channel, taking into account the frequency of unit interrogation.

Current APAS is designed to collect the following data:
− power profile slices;
– power consumption per day;
– meter characteristics (e.g. software version, serial number, number of phases);
– additional parameters (e.g. meter time, current and voltage values by phase, network frequency, the internal temperature of the meter);
– event logs (e.g. turning a meter on/off, time corrections, opening/closing the terminal cover)

Thus, taking into account the structure and purpose of APAS in question, the basic elements of conceptual modeling of data transmission process in such a system are: GSM CSD radio interface, GPRS radio interface, MIR C-01 and SET-4TM electricity meters

3. Conceptual model of the GSM CSD/GPRS radio interface

The GSM CSD radio interface consists of symmetrical channels transmitting data between the network and the client, with reception and transmission spaced out in time. When accessing the resources of the GSM network, each subscriber is allocated only one time interval in the TDMA frame for data transmission at a speed of 9.6 kbps, which remains busy until the disconnection.

The physical layer of the radio interface is modeled using the Okumura-Hata model which is used to determine the attenuation of radio signal propagation and the subsequent calculation of signal-to-noise ratio (SNR) and bit error rate (BER). For modeling the access procedure for network resources, it is proposed to follow the standards for indicators of network service quality, given in RD 45.254-2002 "Standards for indicators of network service quality and methods for their assessment". This document regulates the three quality levels and corresponding probabilities of connection establishment ($P_{CON}$), its inadvertent disconnection ($P_{DIS}$), as well as connection ($T_{CON}$) and disconnection ($T_{END}$) times.

In addition, the data-link layer implements an automatic repeat request (ARQ) procedure when an incorrectly received frame is detected on the receiving end. The error probability of the transmitted frame is mainly determined by bit error rate (BER).

To prevent errors in GSM radio channels, interleaved convolution and block coding are used. The real signal delay time during the channel coding and interleaving stages is between 70 and 80 ms. Radio propagation time forwards and backwards is 233.3 µs. The total propagation-pair delay in the GSM channel caused by signal processing, speech encoding/decoding, channel coding, etc., is about 180 ms [28]. However, taking into account the empirical data given in [29], let us assume that the total delay in the radio channel $t_d$ is a random value with normal distribution with parameters $\mu = 0.83$ and $\sigma = 0.17$

By results of the study of models and approaches to modeling the wireless channel using GSM CSD technology, it is proposed to use the following set of parameters:

1. fixed:
   - total delay in the radio channel ($t_d$);
   - base station transmitter power ($P_{BS}$), 24 dBm;
   - base station antenna gain ($G_{BS}$), 5 dBi;
   - mobile station antenna gain ($G_{MS}$), 3 dBi;
   - frequency of transmission ($f$), 930 MHz

2. configurable during the modeling process:
   - probability of establishing a connection ($P_{CON}$);
   - reconnection timeout ($\Delta t_{CON}$);
   - probability of inadvertent disconnection ($P_{DIS}$);
   - connection time ($T_{CON}$), s;
   - disconnection time ($T_{END}$), s;
   - height of base station antenna ($h_b$), m;
   - height of mobile station antenna ($h_m$), m;
   - distance between the base and mobile stations ($d$), km;

3. changing during the modeling process:
   - signal-to-noise ratio (SNR), dB;
   - bit error rate (BER).
Before transmitting a data block, the mean received signal-to-noise ratio $SNR$ (dB) can be calculated using the formula:

$$SNR = P_{MS} - N,$$

where $N$ is background noise, dB; $P_{MS}$ – average power level of the received meaningful input at the mobile station receiver, dB, calculated in keeping with the ITU-R P. 529-2 recommendation:

$$P_{MS} = P_{BS} + G_{BS} + G_{MS} - L,$$

where $P_{BS}$ is the power of the base station transmitter, dBm; $G_{BS}$ is the base station antenna gain, dBi; $G_{MS}$ is the mobile station antenna gain, dBi; $L$ is the average path loss, dB, calculated according to the Okumura-Hata model, depending on the radio propagation properties.

To find $BER$ (bit error rate) in a channel with Rayleigh fading, the following ratio [30] is used:

$$BER = \frac{1}{2 + SNR}.$$  (3)

The GPRS radio interface consists of asymmetrical channels transmitting data between the network and the client, with reception and transmission spaced out in time. The main difference from GSM CSD technology is that one mobile station can be allocated more than one physical channel, and there is no need to establish a connection. Consequently, resource allocation is dynamic and is characterized by cell load, which is defined using the Erlang B model for systems with refusal. If a mobile station gains access to the environment, it is allocated the maximum available number of physical channels in the TDMA frame, otherwise the subscriber waits for 1 second for the physical channel release.

As with channels using GSM CSD technology, the Okumura-Hata model is used for modeling the physical layer of the radio interface, i.e. to calculate the path loss. Analogously found signal-to-noise ratio makes it possible to subsequently calculate the block error rate (BLER) value using known dependencies between $SNR$ and $BLER$ [31]. In accordance with the block error rate (BLER), a one-time retransmission of an erroneously received packet is performed.

It is proposed to simulate the data-link layer operation of the GPRS radio interface using the Erlang B model. Access to radio channel resources depends on the probability of blocking access to radio resources $P_B$, which is calculated using the formula:

$$P_B = A^n \times N^n$$

where $N$ is the number of physical channels of the base station transmitter; $A$ is offered load (traffic) on the base station, E.

Offered load $A$ generated by subscribers located within the base station can be calculated using the formula:

$$A = \frac{N_{MS} \times \lambda \times T}{3600},$$

where $\lambda$ is the arrival rate per 1 hour; $T$ is the mean holding time, s; $N_{MS}$ – the number of active subscribers within the base station.

For the developed GPRS radio interface model we assume that the holding time per one subscriber is subject to exponential distribution with the average duration of 180 seconds, and the arrival rate is equal to three.

It is possible that the number of active subscribers in an $N_{MS}$ cell may vary, with the value of this parameter being subject to a uniform distribution with $MAX_{MS}$ and $MIN_{MS}$ parameters. Thus, at discrete time the blocking probability for access to radio resources ($P_B$) is calculated using the formula (4). In order to ensure dynamic resource allocation considering the maximum number of slots for both transmission channels ($MAX_{UP\_slot}$) and reception channels ($MAX_{D\_slot}$), a convention is proposed:
As for the GSM radio interface, the encoding delay in the GPRS channel is determined by the
digital signal processor performance and its value varies from 70 to 80 ms.
The delay in packet assembly is caused by the process of encapsulating data packets, since one
packet can contain several data blocks. The encoded data block of the GPRS radio interface is 456
bits. If the size of the transit packet is 128 bytes, 2 data blocks will be encapsulated in one packet.
Therefore, using, for instance, the G.729 codec will result in a delay of 20 ms. A delay of 5 ms is also
added to this value to encapsulate packets in an IP data packet.
Packet transmission delay is equal to the quotient of packet size divided by transmission speed. In
this case, when allocating one physical channel for receiving/transmitting, data transmission speed is
determined by the value of received signal-to-noise ratio at the mobile station, as well as by the coding
scheme used in the terminal. The resulting transmission speed is equal to the product of speed for one
time slot and the number of allocated physical receiver channels.
Network latency occurs during packet transmission and depends on the channels and delivery
protocols, as well as receive buffers for jitter removal that are used in the network. This delay can take
up a significant part of the total delay and amounts to 100-1000 ms in some IP networks. Let us
assume that the value of this delay has a normal distribution with parameters $\mu = 0.7$ and $\sigma = 0.3$.
The delay in data collection is determined by waiting for all data packets to be received and
extracted. Since the size of the data transmission block fits in one packet, then, consequently, the delay
depends on the process of decoding and extraction of the block from the IP packet and is equal to 25
ms.
As a result, the following set of parameters is proposed for modeling GPRS channel characteristics,
similar to those for GSM CSD radio interface model:
1. fixed:
   • radio propagation delay, 2 ms;
   • data encoding delay, from 70 to 80 ms;
   • encapsulation delay, 25 ms;
   • receiver-side data collection delay, 25 ms;
   • base station transmitter power ($P_{BS}$), 24 dBm;
   • base station antenna gain ($G_{BS}$), 5 dBi;
   • mobile station antenna gain ($G_{MS}$), 3 dBi;
   • radio frequency ($f$), 930 MHz
2. configurable during the modeling process:
   • coding scheme ($CS$);
   • maximum number of reception and transmission slots ($MAXD_{slot}$, $MAXUP_{slot}$), pcs;
   • number of frequency channels of the base station ($N_{f}$), pcs;
   • height of base station antenna ($h_{b}$), m;
   • height of mobile station antenna ($h_{m}$), m;
   • distance between the base and mobile stations ($d$), km;
   • maximum number of active mobile stations ($MAX_{MS}$), pcs;
   • minimum number of active mobile stations ($MIN_{MS}$), pcs.
3. changing during the modeling process:
   • signal-to-noise ratio ($SNR$), dB;
   • number of active mobile stations ($N_{MS}$), pcs;
• error probability per data block (Block Error Rate, BLER);
• base station load (A), E;
• probability of blocking access to radio resources (Pb);
• network delay, ms;
• packet delivery time, ms.

Thus, a conceptual description of the GSM CSD and GPRS radio interfaces at physical and data-link layers has been formulated. This representation is the basis for subsequent mathematical formalization of the model using existing modeling approaches.

4. Conceptual model of EM

To simulate the operation of SET-4TM and MIR C-01 meters it is proposed to use the following specified parameters: the list of interrogated parameters, the maximum response timeout, data transmission speed and probability of non-response.

The meters that comprise the system are always slaves, i.e. they cannot transfer information to a channel unless requested by the master device, which is the information-computing complex.

The sizes of requests and responses are not fixed and depend on the request type and meter state. Bytes in request and response sequences must follow each other without time gaps, i.e. the stop bit of the previous byte must be followed by the start bit of the next byte, if there is one. The criterion for the end of any sequence (frame) is a guaranteed timeout, the duration of which depends on the specified data transmission speed.

Working process with the SET-4TM meter is conducted in four stages: link test, session opening, parameter interrogation and session closing. There is link test procedure for the MIR C-01 meter. Interaction of the meter is carried out by means of requests and responses from it. The sizes of requests and responses for the SET-4TM meter are shown in Table 1, for the MIR C-01 meter - in Table 2.

| Table 1. Sizes of requests and responses for the SET-4TM meter. |
|---------------------------------------------------------------|
| **Operation** | **Request size, bytes** | **Response size, bytes** |
| Link channel test | 4 | 4 |
| Session opening | 10 | 4 |
| Reading power profile slices | 8x12 times | 9x12 times |
| Reading data on power consumption per day | 6 | 19 |
| Reading data on meter parameters | 5 | 10 |
| | 5 | 6 |
| | 5 | 13 |
| | 6 | 6 |
| Reading data on additional parameters | 4x6times | 16x6times |
| | 5 | 5 |
| | 4x2times | 16x2 times |
| Event log reading | (4x10 times) | (16x10 times) |
| | ... | ... |
| | (4x10 times) | (16x10 times) |
| Session closing | 4 | 4 |

| Table 2. Sizes of requests and responses for the MIR C-01 meter. |
|---------------------------------------------------------------|
| **Operation** | **Request size, bytes** | **Response size, bytes** |
| Session opening | 19 | 11 |
| Reading power profile slices | 10 | 3 |
| | 14x12 times | 53x12 times |
Tables 1 and 2 show that the power profile slices are read 12 times because two half-hour slices can be read at a time, and since the interrogation is performed once a day, requests and responses will be made the specified number of times.

Events in the SET-4TM counter are stored in circular arrays with [1,10] dimensions - therefore, each array must be accessed ten times in order to read each record. Event logs of the MIR C-01 meter are also implemented as circular arrays with one difference: before reading each record, a request is sent to determine the number of records in the array. In this instance, we assume that each array contains ten records.

Thus, the conceptual model of data transmission process in APAS in question can be represented as a generalized structural chart illustrated in Figure 2.

5. Conclusion
This paper describes a conceptual model of data transmission process in APAS system with the use of GSM CSD channel switching and GPRS packet switching technologies, taking into account the peculiarities of interaction between electricity meters and information-computing complex. In the process of development, the parameters of the system components, electricity meters and communication channels with GSM CSD and GPRS data transmission technologies were defined, and options for calculating the main characteristics of the physical and data-link layers of radio interfaces were proposed based on the analysis of existing models for wireless channels in GSM networks. The modeling of GPRS channels is based on the Okumura-Hata model as well as the Erlang B model, which allow to determine the mean signal-to-noise ratio and the blocking probability respectively. Whereas for CSD digital data channels the Okumura-Hata model and a set of regulated indicators of network service quality are used.

MIR C-01 and SET-4TM devices were used as electricity meters. They differ mainly in the size of requests and responses when interrogating parameters as well as the organization of the interrogation process.
Subsequent mathematical formalization of the conceptual model will allow to simulate information exchange in a system with a predetermined number of channels and their meters and assess the time spent on meter interrogation depending on the variable parameters that are responsible for the configuration of GSM network cells and data transmission quality. The use of such a framework is highly demanded when designing APAS systems to assist decision making, particularly, when deciding on the number of meters that can be interrogated in one or more channels using the aforementioned data transmission technologies.

6. References

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