Metrol. Meas. Syst., Vol. XX (2013), No. 3, pp. 337–350.

METROLOGY AND MEASUREMENT SYSTEMS
Index 330930, ISSN 0860-8229
www.metrology.pg.gda.pl

SOME PRACTICAL PROBLEMS OF COMMUNICATIONS RELIABILITY IN ENVIROMENTAL MONITORING SYSTEMS

Bogdan Dziadak[1], Lukasz Makowski[1], Andrzej Michalski[1,2]

1) Warsaw University of Technology, Institute of Theory of Electrical Engineering, Measurement and Information Systems, Koszykowa 75 00-662 Warsaw, Poland (✉ anmi@iem.pw.edu.pl)
2) Military University of Technology , Institute of Electronic Systems, Gen. Sylwestra Kaliskiego 2, 00-908 Warsaw, Poland

Abstract

In this paper, some issues of building a reliable, distributed measurement system for monitoring of water quality in reservoir Lake Dobczyckie are presented. The system is based on a measurement station that has the shape of a floating buoy which is supposed to be at anchor on the reservoir. Wireless data transmission problems that were encountered during the development of the buoy, modeling a radio link, and measurements of actual signal strength on the reservoir are discussed. A mathematical approach to procedures of early situation assessment was conducted, and specialized procedures were designed for measurement stations of the system. It is also discussed how such computations can improve a qualitative assessment of system performance in terms of real-time messaging.

Keywords: Monitoring systems, GSM communication, floating buoy, real-time messaging.

1. Introduction

Measurement systems for environmental monitoring differ in size and complexity, spanning dozens or even hundreds of kilometers [1] – [3]. Due to such variation there is no unique way to create a common methodology for construction of such systems. Some distributed systems based on WSN and a communications link connected with this technology [4] - [7]. However, one universal approach is to use the GSM network as a link between distant measurement devices and data visualization equipment of system users [8] – [11]. The use of GSM/GPRS brings all advantages of a typical network based on TCP/IP from data transmission reliability to well known programming practices [12]. However, as for a wireless measurement system, typical GSM modules use a lot of power which is their most important disadvantage [13]. From the user's point of view, beside the hardware selection, the most important issue of analysis is the establishment of stable GPRS communications and early assessment of the situation. Such stable GPRS communication will be analyzed in the article with the use of the Okumura-Hata approach.

Early assessment of the situation is particularly important in the case of environmental monitoring. In typical systems, data is usually sent immediately after it becomes available on nodes of the measurement system, and it becomes an entry in database as quickly as possible. This provides an opportunity for instant monitoring of environment in at least a few, most important parameters. Each measurement station can compute a numerical representation of situation assessment. With values reaching predefined bounds, the rate of measurements of a given parameter might be increased to obtain finer characteristics of change. Therefore these early calculations create estimations of risk of water pollution. Having them combined should improve the time of reaction to a dangerous situation compared to decisions made from some central point of data collection, remote to the problem occurrence. A new approach to this

Article history: received on Jan. 23, 2013; accepted on May. 25, 2013; available online on Sep. 15, 2013; DOI: 10.2478/mms-2013-0029.

problem will also be taken into consideration. Considering requirements of dependable data transmission in soft real-time, which is typical for on-line monitoring systems, both hardware and software issues as unequivocally important. Therefore to provide a dependable solution, the problem of communications reliability should be divided into several layers. The presented research is based on the assumption that TCP/IP is available, and on top of that a more sophisticated, standardized protocol for message passing might be used. In our solution we base communications on XMPP whose applications, including measurement systems, are numerous as it is XML compliant.

The following chapter is a discussion of some practical remarks on creating a reliable ISM-band radio link between a mobile station based on the floating buoy and the measurement system. The next chapter provides a description of an approach to create data-based soft real-time messaging with the rate adjusted to current parameters of the environment. The presented article is a discussion of the wireless measurement system for monitoring environmental parameters that was actually tested on reservoir Lake Dobczyckie.

2. Communication structure

In case of the presented system for monitoring of reservoir Lake Dobczyckie, according to the GSM providers assurances, the GSM/GPRS connection should be available on the reservoir area. However, after first field experiments with the measurement station working on the reservoir, several serious problems have appeared. Reservoir Lake Dobczyckie is an artificial reservoir in a precipitous valley with a solid stone shore. The GPRS connection was not stable: there were unexpected interruptions and breaks in transmission, and finally in the software that was controlling the station a procedure was implemented that could restart communication without human intervention. The problem was extensively analyzed and few possible origins of the issue were found:

- poor quality of connection between the GSM modem and station controller and antenna,
- too low position of the antenna which could have been screened by thick fog which often forms there,
- the distance between the measurement station and the GSM Base Transceiver Station (BTS) was too great.

During maintenance of the station, the first problem was eliminated. However, it was necessary to change the equipment to one that was designed for operations in harsh weather conditions, which means taking into consideration the temperature range and high humidity. The second and the third issues mentioned above, were the subject of simulation and measurements of real signal strength. Firstly, conditions for stable GPRS communication were modeled with the Okumura-Hata model. Secondly, a series of measurements on reservoir Lake Dobczyckie was performed to find the actual value of the received signal strength indication (RSSI). Comparison and discussion of both the theoretical and practical approach provides a broader view of the problem.

2.1. Modeling communications with the Okumura-Hata approach.

Existing radio wave propagation models help to create a radio link budget. In [14] a propagation model for a mobile user is presented. Authors in [15], [16] focus on wave propagation and attenuation in arboreous areas while in [17] a modern model for urban area is shown.

In the presented project the authors used the Okumura-Hata model which is one of the principal propagation models, especially for countryside areas [18]. With the Okumura-Hata propagation model it is possible to approximate the strength of the signal received by a mobile station at some given distance from the BTS. The restrictions we used in the Okumura-Hata model were:

- distance (R) from the base station: from 1 km to 20 km,
- height of base station antenna (h_{BS}): from 30 m to 200 m,
- height of mobile antenna (h_{MS}): from 1 m to 10 m,
- carrier frequency (f_c): 150 MHz to 1500 MHz.

Hata created a number of mathematical models for countryside, suburban and urban areas. Signal attenuation for the third of them is illustrated by equation (1):

$$L_{urban}(dB) = 69.55 - 26.16\log_{10}(f_c) - 13.82\log_{10}(h_{BS}) - a(h_{MS}) + \\ + (44.9 - 6.55\log_{10}(h_{BS}))\log_{10}(R) \quad , \tag{1}$$

where a is correction factor depending on the urbanization level. Its value for a small city is given by equation (2):

$$a(dB) = (1.1\log_{10}(f_c) - 0.7)h_{MS} - (1.56\log_{10}(f_c) - 0.8). \tag{2}$$

Signal loss in open area might be calculated with equation (3):

$$L_{open} = L_{urban} - Q_r \, . \tag{3}$$

Factor Q_r is used to correct the small city formula for suburban and countryside (open) area. For an open area Qr is given by equation 4:

$$Q_r(dB) = 4.78(\log_{10}(f_c))^2 - 18.33\log_{10}(f_c) + 40.94 \, . \tag{4}$$

In all equations f_c is expressed in MHz, and the distance R in km, while h_{MS} and h_{BS} are in m.

The measurement station antenna is positioned 1 m above the water surface level and has a gain value $G_{RX} = 0dBi$. As Lake Dobczyckie is within the range of four BTS stations, the distance between the measurement station and a particular BTS varies from 1 km to 6 km. We assume that the BTS transceiver power is 20 W (43 dBm), the antenna is positioned 20 m above ground level and its gain equals $G_{TX} = 16dBi$. Using the Friis formula given by equation (5) and the Okumura-Hata model it is possible to calculate the signal strength received by the measurement station GSM modem:

$$P_{RX}(dB) = P_{TX}(dB) + G_{TX} + G_{RX} + L \, , \tag{5}$$

where P_{TX} is the power transmitted by the transceiver.

RSSI as a function of distance between the measurement station and the BTS is presented in Fig. 1. The dark, solid line illustrates *RSSI* values from measurements that the authors performed on the reservoir. We assume *RSSI* equal to - 68dBm as the minimum level necessary for flawless operation of GPRS communication. In Fig. 1 this level is represented by the horizontal line. As reference there are also shown characteristics for: vacuum space, rural area, and urban area.

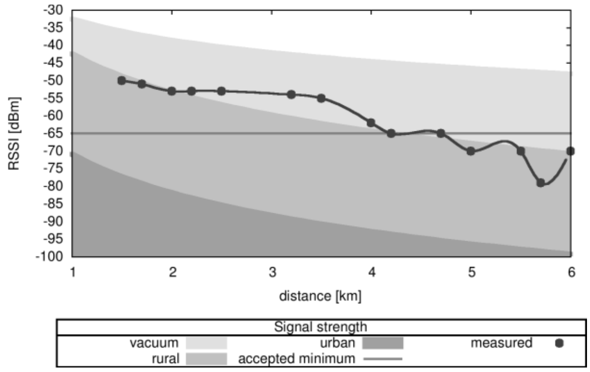

Fig. 1. Received signal strength as a function of distance from the BTS.

2.2. Measurements of RSSI on the reservoir

The measurement station was based on an industrial microcomputer Moxa W345 which has an integrated GSM modem capable of providing class 10 GPRS, which makes Internet connection and advanced protocols available. Results of theoretical analysis had to be confronted with tests of the real *RSSI* available in the system deployment area on the reservoir. During these tests that were made in Summer 2011, the weather was unfavorable for radio transmission – cloudy days, fog alternated with showers. However, it is obvious that the system must be operational irrespective of weather conditions, so values obtained then are even better than those on a bright, sunny day. During the tests, the authors estimated the suitable level of *RSSI (-61dBm)* needed to maintain proper GPRS communication.

After processing the raw data it was possible to create a map of RSSI that is shown in Fig. 2. The darker the spot is, the more damped GSM signal at this place was observed. Only the area within the scope of measurement system final user interest was tested and all other is left white. The measured values were put onto a map and then blended with the use of a Gaussian filter. What is important, on the map are not specific values but a general characteristic of problems that the authors encountered while setting up the system.

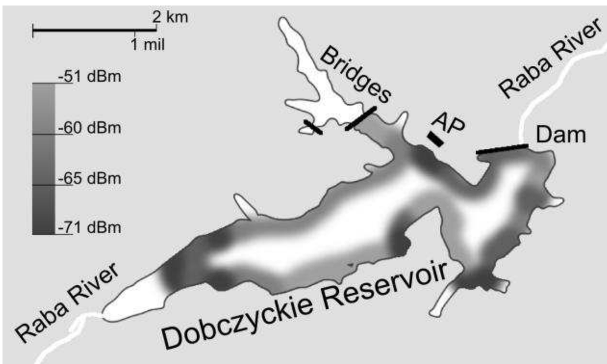

Fig. 2. RSSI on the reservoir Lake Dobczyckie.

There are severe irregularities in GSM signal propagation on the reservoir. In some areas where a measurement station is needed, the signal strength is too weak to sustain reliable communication. It usually happens at bays or where the shore is substantially sloped. In this system an unexpected loss of connection is inadmissible, therefore communications must be ensured by another way, such as a short to medium range radio link.

2.3. Mid-range communication

To improve the communications quality between measurement stations and the system server we decided to create an ”access point” (AP) on the reservoir shore. The objective of this system element is routing information from a measurement station towards the system database server. One of its interfaces is a GSM/GPRS or wired connection to the Internet while the other interface is a radio link with the floating buoy. The task was to choose an optimal short range radio communication standard without increasing operational costs.

A radio connection based on a directional antenna was not feasible due to several reasons. The measurement station is prepared to be anchored on the bottom of the reservoir yet it is still floating on the water surface and therefore can rotate freely or even slightly change its position. Furthermore the water level in Lake Dobczyckie can vary as much as 7 m. Moreover, the AP should work with several stations positioned in different parts of the reservoir. Therefore all antennas must be omnidirectional. Based on these limitations, it was possible to consider one of radio link standards that are shown in Table 1.

Table 1. Radiolink standard.

	Band [MHz]	f_w [kHz]/channels	t_a [%]	EIRP [mW]	Throughput
1.	143 – 174	25 kHz	100	-	19.2 kbps
2.	218 – 238	25 kHz	100	-	19.2 kbps
3.	380 – 400	25 kHz	100	-	19.2 kbps
4.	433	25 kHz/8	10	10	19.2 kbps
5.	868	25 kHz/10	10	500	72 kbps
6.	2400	20MHz/13	100	100	54 Mbps
7.	5100	20MHz/11	100	200	54 Mbps

The first three standards listed in Table I are for a band which unfortunately is licensed in Poland and a considerable fee is required. However, other interfaces work in free of charge ISM bands and for all of these standards we calculated link budgets assuming that to each modem there is connected a $\lambda/4$ antenna with 0dBi gain and an omnidirectional radiation pattern, and the antenna of the measurement station is positioned 2 m above the water surface. The Friis equation and the Okumura-Hata model were used to calculate link budgets for standards in range from 143MHz to 1500MHz. An exception was IEEE 802.11 (WiFi) for which only the Friis equation was applied. Results are presented in Fig. 3.

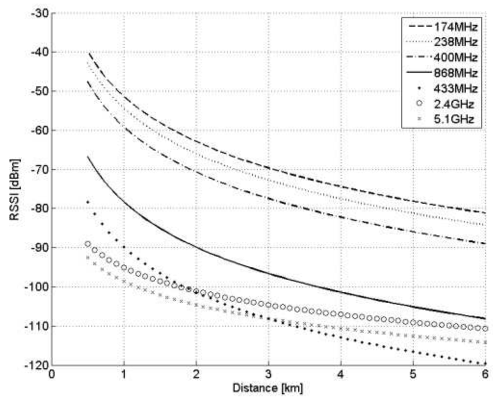

Fig. 3. Received signal strength as a function of distance between the AP and the measurement station for different standards.

The maximum distance of communication for above standards is presented in Table 2. The distance was determined in relation to RSSI and sensitivity of a modem receiver.

Table 2. Maximum possible distance of communication.

	Band [MHz]	Transmitter power [dBm]	Receiver sensitivity [dBm]	Max. distance [km]
1.	143 – 174	10	-115	>15
2.	218 – 238	10	-115	>15
3.	380 – 400	10	-115	>15
4.	433	-20	-100	0.4 – 0.8
5.	868	-3	-110	6.6
6.	2400	-10	-96	0.8
7.	5100	-7	-100	1.5

The greatest distance is for cases 1 – 3, which unfortunately are licensed in Poland. To avoid costly fee and administrative procedures we have chosen for further investigation the 868 MHz band. Modems for this frequency are popular, cheap and consume little power which is important for a station that has to work without a power line and only on a battery sustained by a renewable energy source.

We conducted a test to determine the real communications span. We used modems whose maximum transmission power was 500mW, the modulation used was complementary code keying CCK. During the test, the Access Point periodically, every 200ms, sent a control data packet to the mobile station. Maximum range communication was determined when the received data (from a mobile station) had more than 1% of errors.

On the mobile station an omnidirectional $\lambda / 4$ antenna with 0 dBi gain was installed. The Access Point was tested with three different antennas and results of this experiment are presented in Fig. 4. The first test was with an omnidirectional $\lambda / 4$ antenna with 0 dBi gain with which it was possible to have communication on a range up to 1150 m. This is "case a" in Fig. 4. The second one was with an omnidirectional and collinear antenna $6 \times \lambda / 4$ having 8.5 dBi gain. This increased the communication distance up to 3400 m (case b in Fig. 4). This antenna with its vertical radiation pattern is presented in Fig. 5. Alternatively a directional antenna can be used, a beam aerial with 10:5 dBi gain, and half power beam width (HPBW) equal to 60^0. This change increased the communication range only slightly up to 3800 m (case c in Fig. 4). The antenna and its horizontal radiation pattern is presented in Fig. 6.

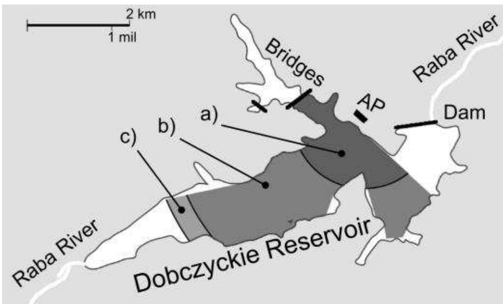

Fig. 4. 868 MHz radio-link. a) colinear, 0 dBi gain b) colinear, 8.5 dBi gain c) beam aerial, 10.5 dBi gain.

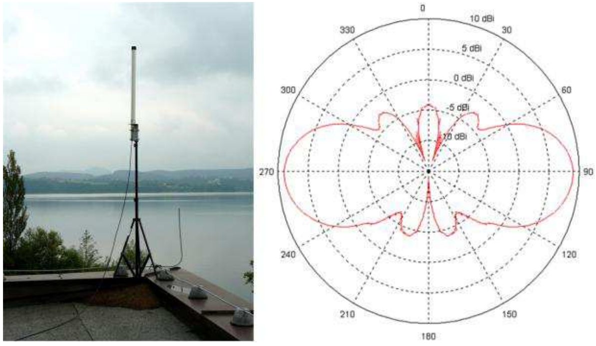

Fig. 5. Test installation of collinear antenna $6 \times \lambda / 4$ with 8.5 dBi gain and its vertical radiation pattern in free space.

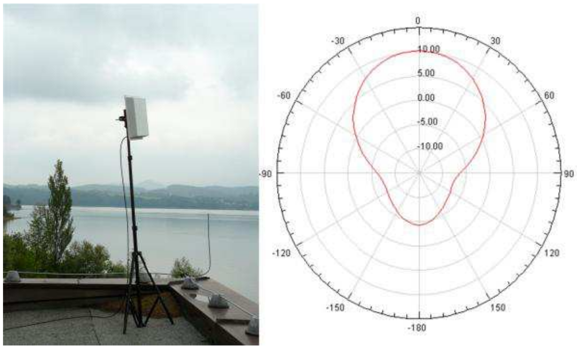

Fig. 6. Test installation of beam aerial and its horizontal radiation pattern.

All antennas were tested in the same conditions in a short time span. Reasoning both from practical observations and from theoretical analysis of several wireless transmission types, mid-range communication in the 868 MHz band complemented with GSM/GPRS for connection with the measurement system database server has been chosen. Eventually the communication structure of the system in the part that runs on the lake is shown in Fig. 7. Having a reliably working hardware, the implications of distributed, autonomous data processing in system nodes have been investigated.

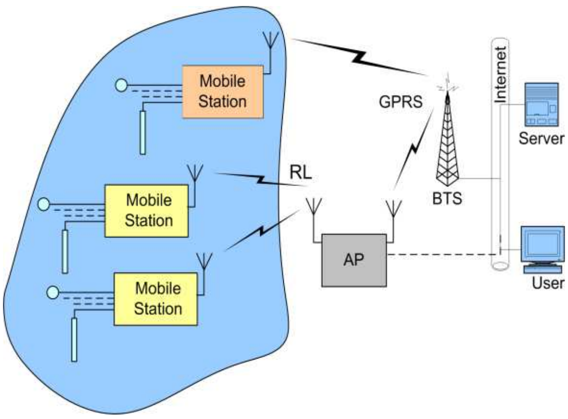

Fig. 7. Wireless communication of the measurement system on Lake Dobczyckie.

3. Early assessment of the situation

The main assumption was that the presented system is using data transmission under bounds of soft real-time conditions. This means that data is usually sent immediately after it becomes available on the measurement station, and it becomes an entry in the database as quickly as possible. This provides an opportunity for instant monitoring of water quality in at least few most important parameters mentioned before. Such a station becomes part of a distributed, highly scalable and vital decision support system [6]. Each measurement station can compute the numerical representation of situation assessment. With values reaching predefined bounds, the rate of measurements of a given parameter might be increased to obtain finer characteristics of change. Therefore these early calculations create a distributed estimation of risk of water pollution. Having them combined should improve the time of reaction to a dangerous situation compared with decisions made from some central point of data collection remote to the problem.

Expression $k(x)$ is a model that shows how much a given water parameter is unacceptable in terms of water quality. From that function we disjoin two simpler factors k_a(y) and k_b(y) which are, respectively:

1. Each measured value x_m of a given water parameter has safe boundaries (x_{min}; x_{max}), and within them there is some level which might be considered to be the most desired value x_d of the given parameter. The further from this good point, the worse the state of water, and the more important this information. In a special case x_d might be the midpoint of x_{min} and x_{max} although in general it is an arbitrary point within these boundaries.
2. A significant change of parameter is also an important event thus it should also increase the importance of a message. It might be obtained by difference quotient calculation.

Both factors must be normalized before comparison. Therefore we normalize the measured value x_m within boundaries (x_{max}; x_{min}):

$$\begin{aligned} \forall x_m \in (x_{min}, x_d) \quad & x = \frac{|x_d - x_m|}{x_d - x_{min}} \\ \forall x_m \in (x_d, x_{max}) \quad & x = \frac{|x_d - x_m|}{x_{max} - x_d} \end{aligned} . \tag{6}$$

When $x_m = x_d$, x equals 0 therefore the primary rate of measurements of this parameter is not affected by its value. In cases where $x_d \equiv x_{min}$ or $x_d \equiv x_{max}$, x equals 1.

For x_m exceeding boundaries, the calculation is as follows (7):

$$x = \frac{|x_d - x_m| + X_{max} - X_{min}}{X_{max} - X_{min}} . \tag{7}$$

For function $k_a(x)$ we consider an inverted and upraised hyperbolic secant to be a good basis. The hyperbolic secant will hide small changes within some radius around point x_d and it will also elevate the function result in situations where the measured values are reaching or exceeding a critical maximum or minimum value. The proposed equation is given by formula (8):

$$k_a(x) = 1 - sec\,h(nx) = \frac{(e^{nx} - 1)^2}{e^{2nx} + 1} . \tag{8}$$

Parameter n is for normalization of the equation within the boundaries for which $x \in (0;1\rangle$. This operation is necessary for reasonable comparison between $k_a(x)$ and $k_b(x)$. Simplifying equation (8) against x = 1 and an arbitrarily chosen $k_a(x)$ = 0,8 results in a simple quadratic equation found with a positive value of $n = log(2\sqrt{6} + 5) \cong 2{,}29$. For the factor $k_b(y)$ we can use the formula of (8) but with parameter $x := y$ where y is defined as (9):

$$y = \frac{x_{(m,0)} - x_{(m,t)}}{x_{max} - x_{min}}. \tag{9}$$

There is a recently measured value $x_{(m;0)}$, and an earlier value $x_{(m;t)}$. In this approach, the time between these two measurements should be constant to keep the calculation of $k_b(y)$ consistent all the time. However, the measurement frequency can change which makes this condition impossible to be met. We consider that this problem might be successfully dealt with by using an approximation based on the assumption that in a short time the change of a parameter value is close to linear. Having a previous measurement at time k and a recent one at time 0, the estimated value at time t is given by (10):

$$x_{(m,t)} \approx x(m,k) + \frac{t}{k}\left(x_{(m.0)} - x_{(m,k)}\right). \tag{10}$$

Factor $k_b(y)$ is considered to have a smaller impact on the final situation assessment than $k_a(x)$ as it is more susceptible to noise. Furthermore in equation (9) the numerator is usually smaller and the denominator is larger, compared with typical cases for $k_a(x)$. Eventually, having both parameters normalized we take into account a root mean square value of them as an initial assessment of situation function (11):

$$k(x) = \sqrt{k_a(x)^2 + k_b(x)^2}. \tag{11}$$

We consider $k(x)$ as an evaluation of the consolidated risk function that something bad is happening with parameters of water in the reservoir.

3.1. Real-time messaging with adaptive measurement period

The existence of a message that provides information on the measured parameter x might be modeled as a unit step function (the Heaviside function) that triggers a response of the messaging subsystem. Each successful information retrieval from a message is beneficial to end users of the measurement system. This gain might be defined as some function $G_x(t)$, where t is always a positive difference between message receiving time and message creation time. We assume that the value of the profit degrades monotonically with increasing message transmission and processing time. There are two time limits by which a message should be processed:

- Variable deadline T_1, related to factor f that is a previously computed importance of the message.
- Fixed and parameter-related deadline T_2 which should not be overrun, neither by an automated system nor by a chemical laboratory.

Deadline T_1 indicates that the more important the message, the higher the gain from receiving it quickly. The value of deadline T_1 is limited by T_2 which comes later. Deadline T_2 might be obtained from acts of law that define procedures for laboratories responsible for the quality of household tap water. As traditional methods based on water sampling and laboratory procedures are quite slow, in comparison to automated systems, these rates are many hours or even days long, and are parameter-specific. However, some formula is needed to evaluate messaging system reliability. The gain function should be normalized to the range $(0;1\rangle$. It is equal to maximum starting from the moment that the message was created, and then it drops asymptotically to zero, having two time constants that are equal to deadlines T_1 and T_2. Therefore the gain function in this soft-real time messaging system can be modeled as a slightly modified second-order inertial block, given by equation (12).

$$G_x(t,T_3,T_4) = \frac{1}{T_3 - T_4}\left(T_3 e^{-\frac{t}{T_3}} - T_4 e^{-\frac{t}{T_4}} \right), \tag{12}$$

where:

$$T_3 = \frac{T_2}{2} + \sqrt{\frac{T_2^2}{4} - T_1^2}\ , \tag{13}$$

and:

$$T_4 = \frac{T_2}{2} - \sqrt{\frac{T_2^2}{4} - T_1^2}\ . \tag{14}$$

Time constants T_1 and T_2 were discussed above. Because T_1 is under square root and the result should be real, the constraints on first deadline can be concluded as: $T_1 \in \left(0, \frac{T_2}{2}\right)$. Then T_1 can be calculated simply as:

$$T_1 = \left(0{,}5 - \frac{k(x)}{2}\right) T_2 . \tag{15}$$

Because $k(x) \in (0;1\rangle$ then it is guaranteed that T_1 value will never exceed the limit. The plot of the value gain function at point $t = T_2$ in relation to ratio T_1/T_2 is presented in Fig. 8.

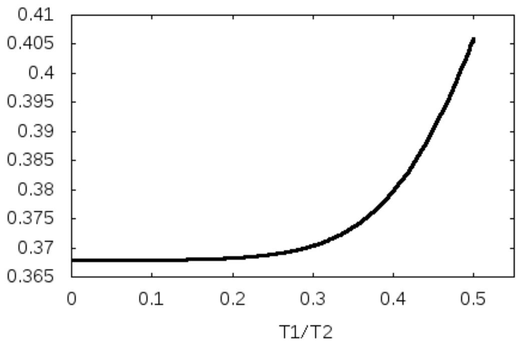

Fig. 8. Gain value at t = T_2 in relation to the T_1/T_2 ratio.

After mathematical transformations of the gain function one may conclude that:

$$\lim_{T_1 \to 0} G_x = e^{-1} \approx 0.368 \text{ and } \lim_{T_1 \to \frac{1}{2}T_2} G_x = 3e^{-2} \approx 0.406 .$$

It is an interesting and useful fact that the gain value at time $t = T_2$ almost does not depend on the value of T_1. A message received as late as on the second deadline provides an approximately constant gain value. Therefore the presented approach is reliable and predictable, thus suitable for decision making.

Equations 6-15 were formulated analytically, in an iterative process, with testing against existing real data, and water value constraints.

B. Messaging Reliability Estimator Concluded From the Gain Function

The reliability of water data gathered by the station depends first and foremost on regular and proper sensor calibration. However, there exists a possibility that a malicious person may try to circumvent the measurement system to cause a false alarm (false positive) or to prevent action against planned and intentional water poisoning (false negative). As the data transmission is secured by connection encryption, an attacker has the option of damaging the buoy itself. We admit that the possibility of such an attack exists in all environmental measurement systems including ours, and against such a direct physical attack we have little or no countermeasures. However, the Dobczyckie Reservoir area is closed to public access, and monitored by Water Police.

System functioning might be evaluated in terms of reliability. One may decide to calculate the average value of the gain function for recent n messages, or for messages received recently. Worst case, best case, and jitter can also provide an insight to messaging subsystem processing quality. Possibilities are numerous and easy to create so we will not discuss them further.

However, one may observe that it is hard to calculate the gain value for a message which was never received as in the receiving server it is even unknown if such a message was ever created. The gain function is to estimate a working messaging system and the case where messages are completely lost is much more severe than a situation with messages simply more or less delayed. It should be observed by other means and dealt with accordingly. It is possible to relay gain for such messages in a known maximum period of measurements given by deadline T_2. If the message was not received within this time span, the gain is calculated as for a message that was received after $t \geq T_2$.

4. Results

Measurements were initially started on 15th of December 2011 in laboratory tests. Then the system was gradually developed and the buoy was equipped with more and more sensors. Now there are 29 logical sensors. 17 of them are for environmental measurements while the other are for buoy introspective measurements and self-testing. There is also a GPS that provides time and position information but we do not count it as a sensor because it is a "must-have" feature that is providing meta-data for each database entry. Finally, the first buoy was successfully deployed on Dobczyckie Reservoir on 4th of July 2012. Since that launch, to the mid of May 2013 more than 250 thousand database entries were created, each with one measurement value. In Table 3 we present a list of sensors, including buoy self-test sensors, and the number of entries per each of them as for 24th of May 2013.

It is not possible to present such a data set in the article. However, a small sample might be shown.

In Table 4 we have shown an excerpt from the database for turbidity characteristics that was measured by a buoy positioned on Dobczyckie Reservoir. This piece of data was chosen as it contains several interesting events and values. It was assumed that NTU values should be in the range from 1 to 8 and anything outside these limits is supposed to be an anomaly. At the beginning the measurement procedure was triggered every 6-7 minutes. But then an incident happened shown at position 7 after which the rate was increased to about 4-5 minutes. The rate was adjusted gradually upon the difference between the measured value and the average of limits.

Table 3. Sensors and number of database entries provided by them (counted 24th of May 2013).

Sensor	Number of values measured (database entries)
Accelerometer	4152
Accelerometer – X axis	4153
Accelerometer – Y axis	4145
Accelerometer – Z axis	4148
Position – heading	4144
Position – pitch	4143
Position – roll	4142
Fuel cell voltage	6101
Power driven from fuel cell	4155
Fuel cell output current	4309
Fuel cell usage time	4152
Anemometer	4081
Anemoscope	4081
Air thermometer	8179
Insulation sensor	13265
Humidity (relative) sensor	7465
Weather station battery voltmeter	9073
Weather station power supply voltmeter	8408
Weather station battery temperature	4444
Weather station (buoy) internal temperature	4349
Multisensor battery voltage	4645
Chlorophyll sensor	18654
Dissolved NH4 sensor	19558
Dissolved NH3 sensor	21617
Conductometer	18591
Turbidimeter	17367
Water thermometer	15179
Water reaction (pH)	17823
Dissolved chlorine sensor	19724

Table 4. Sample measurements.

No	Measurement date	Turbidity [NTU]	Importance value k [-]	Delay [s]	Gain function value G [-]
1	2012-11-01 00:02:51	6,7	0,05	4	0,97
2	2012-11-01 00:09:32	6,2	0,03	7	0,92
3	2012-11-01 00:16:32	7	0,06	8	0,89
4	2012-11-01 00:23:22	6,7	0,05	7	0,91
5	2012-11-01 00:30:31	6,5	0,04	5	0,95
6	2012-11-01 00:37:32	6,4	0,04	3	0,98
7	2012-11-01 00:44:33	13,4	0,35	8	0,84
8	2012-11-01 00:48:01	6,6	0,34	13	0,71

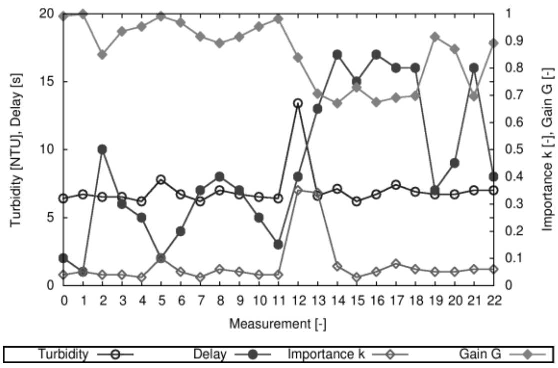

Fig. 9. Sample measurements and their transmission delay, importance value k and gain value G.

The incident and the following measurement were considered to be of higher importance than measurements of typical values as it is presented in the column for value *k*. Despite the higher importance of the incident this message gain function value is surprisingly low compared for example to the previous message at position 6. It happened so due to the fact that delay in transmission was longer. If we compare measurements at position 7 and the one at position 3 we can also observe that a value of less importance provides a higher gain function even though the delay is the same. It is so as for an excessive value, where the importance *k* is high, it is anticipated that the message will be passed immediately. It did not happen and therefore the gain provided by message 7 is relatively lower than the one for some other messages including one at position 3. We may also observe that measurements numbered as 8 to 10 were exceptionally late and therefore their gain function values are considerably lower than for other measurements.

From Table 4 we see that both the importance value k and delay in data transfer both affect the gain function. A larger excerpt of turbidity data that was measured around that time is presented in Fig. 9.

5. Conclusion

A critical aspect of each distributed wireless system for environmental monitoring is reliability of data transmission. The first topic of the article are practical problems of wireless communication in a distributed measurement system that the authors are building for a waterworks company. It was shown how the problems encountered were dealt with, both by a theoretical approach with Okumura-Hata modeling, and by actual measurements of signal propagation on reservoir Lake Dobczyckie. The feasibility of wireless communication on the reservoir with the use of a GSM/GPRS commercial network (in GSM900 standard) and free ISM band (868 MHz) have been discussed. The second topic presented in the paper is related to the logical layer of communication. As a result of conducted research, a new equation for early estimation of water quality that can be calculated even with a measurement station with limited computing power, was proposed. Data transmission from measurement stations should be done instantly or in other words as a soft real-time process. For real-time processes a gain function must be defined which describes how valuable is finishing some processes within particular time bounds. The authors proposed to base the gain function on the early situation assessment. Therefore reception of each message might be valued not only on the delay in transmission but also on the importance of a particular measurement that the message brings. After some modifications this general idea might be applied to other realtime measurement systems, for environmental protection as well. In the paper it was shown that a comprehensive approach both to hardware and to the logic of measurement system communication is necessary to create a reliable solution working in realtime conditions.

References

[1] Dziadak B., Makowski Ł., Michalski A. (2011). Environmental monitoring system with instant communication. *Przegląd Elektrotechniczny*, (4), 243-245.

[2] Kotus J., Szczodrak M., Czyżewski A., Kostek B. (2012). Distributed System for Noise Threat Evaluation Based on Psychoacoustic Measurements. *Metrology and Measurement Systems,* XIX(2), 219-230.

[3] Ray S., Venayagamoorthy G.K. (2008). Real-time implementation of a measurement-based adaptive wide-area control system considering communication delays. *Generation, Transmission & Distribution, IET*, 2(1), 62-70.

[4] Ferrari P., Flammini A., Sisinni E. (2011). New Architecture for a Wireless Smart Sensor Based on a Software-Defined Radio", *IEEE Transaction on Instrumentation and Measurement*, 60(6), 2133-2141.

[5] Derr K., Manic M. (2011). Extended Virtual Spring Mesh (EVSM): The Distributed Self-Organizing Mobile Ad Hoc Network for Area Exploration. *IEEE Transactions on Industrial Electronics*, 58 (12), 5424-5437.

[6] Sardini E., Serpelloni M. (2011). Self-Powered Wireless Sensor for Air Temperature and Velocity Measurements With Energy Harvesting Capability. *IEEE Transactions on Instrumentation and Measurement*, 60 (5),1838-1844.

[7] A.M. Abdelgawad, A.M. Bayoumi, M.A. (2011). Remote Measuring for Sand in Pipelines Using Wireless Sensor Network. *IEEE Transactions on Instrumentation and Measurements*, 60 (4), 1443-1452.

[8] Stefański J., (2012). Radio Link Measurement Methodology for Location Service Application. *Metrology and Measurement Systems* XIX(2), 333-342.

[9] A. Flammini, A., Marioli D., Sisinni E., Taroni A. (2007). Environmental Telemonitoring: A Flexible GSM-DECT-Based Solution. *IEEE Transactions on Instrumentation and Measurements*, 56 (5), 1688-1693.

[10] Lasfer A., Chreide A., Abu Ouda H. (2011). GRPS-based Distributed Home-monitoring Using Internet-based Geographical Information System. *IEEE Transactions on Consumer Electronics*, 57 (4), 1688-1694.

[11] Al-Ali A.R., Zualkernan I., Aloul F. (2010). A Mobile GPRS-Sensors Array for Air Pollution Monitoring. *IEEE Sensors Journal*, 10 (10), 1666-1671.

[12] Dziadak B., Makowski Ł., Michalski A. (2011). Embedding Wireless Water Monitoring System in Internet. *Przegląd Elektrotechniczny*, (4), 246-248.

[13] Dziadak B., Michalski A. (2011). Evaluation of the Hardware for a Mobile Measurement Station. *IEEE Transactions on Industrial Electronics*, 58 (7), 2627-2635.

[14] Atia M.M, Noureldin A., Korenberg M.J. (2011). Dynamic Propagation Modeling for Mobile Users' Position and Heading Estimation in Wireless Local Area Networks. *IEEE Wireless Communications Letters*, 1 (2), 101-104.

[15] Seker S., Kunter F.C. (2011). Multi-Components Mobile Propagation Model of Park Environment. *IEEE Transaction on Magnetics*, 47 (5), 1494-1497.

[16] Azevedo J.A.R., Santos F.E.S. (2011). An Empirical Propagation Model for Forest Environments at Tree Trunk Level. *IEEE Transactions on Antennas and Propagation*, 59 (6, part 2), 2357-2367.

[17] Saeidi C., Fard A., Hodjatkashani F. (2012). Full Three-Dimensional Radio Wave Propagation Prediction Model. IEEE Transaction on Antennas and Propagation, 60 (5), 2462-2471.

[18] Hata H. (1980). Empirical Formula for Propagation Loss in Land Mobile Radio Services. *IEEE Transactions on Vehicular Technology*, VT-29 (3), 317-325.

[19] Makowski Ł., Michalski A. (2012). Measurement systems as foundations for reliable decision support systems. *IEEE Instrumentation and Measurement Magazine*, 15 (3) 48-52.