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SERVICE QUALITY MANAGEMENT IN MICROCLOUD-BASED IoT INFRASTRUCTURE

ZARZĄDZANIE JAKOŚCIĄ USŁUGI W INFRASTRUKTURZE IoT BAZOWANEJ NA MIKROCHMURZE

Abstract

The Internet of Things (IoT) is an emergent technology that offers great opportunities to enhance economic indices and productivity of enterprises, to improve the quality of consumers' lives, and to enable more efficient use of resources. In this paper, the authors propose an approach to Microcloud-based IoT infrastructure management to provide the desired quality of IT services with rational use of IT resources. Efficiency of IoT infrastructure management can be estimated by the quality of services and the management costs. The task of operational service quality management is to maintain a given level of service quality with the use of minimum IT resources in IoT environment. The proposed approach allows the efficient use of resources for IT services' provision in IoT ecosystem through the implementation of service level coordination, resource planning and service level management processes in an integrated IT infrastructure management system.

Keywords: cloud, microcloud, decomposition-compensation approach, coordinator, resource allocation problem, datacenter

Streszczenie

Internet przedmiotów (IoT) to wschodząca technologia, która oferuje duże możliwości zwiększenia wskaźników ekonomicznych i wydajności przedsiębiorstw, poprawia jakość życia konsumentów, a także umożliwia bardziej efektywne wykorzystanie zasobów. W niniejszym artykule autorzy proponują podejście do zarządzania infrastrukturą IoT na bazie mikro w celu zapewnienia pożądanej jakości usług IT z racjonalnym wykorzystaniem zasobów IT. Efektywność zarządzania infrastrukturą IoT może być określona przez jakość usług oraz koszty zarządzania. Zadaniem zarządzania jakością usług operacyjnego jest utrzymanie określonego poziomu jakości usług z wykorzystaniem minimalnej ilości zasobów IT w środowisku IoT. Proponowane podejście pozwala na efektywne wykorzystanie zasobów do świadczenia usług IT w ekosystemie IoT poprzez realizację koordynacji poziomem usług, planowania zasobów i procesów zarządzania poziomem usług w zintegrowanym systemie zarządzania infrastrukturą IT.

Słowa kluczowe: chmura, mikrochmura, podejście dekompozycji-kompensacji, koordynator, problem alokacji zasobów, centrum danych

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1. Introduction

The IoT facilitates new possibilities in many industries and creates additional load on the datacenter due to the additional number of devices being placed into the network and enormously increasing demand of data exchange and processing. IoT turns out to be much more complex than just deploying new applications, connecting more computers, mobile devices and sensors to the network.

Given the current challenges, which are created by the IoT spreading, enterprises will need to take into account relevant technology deployments and implement internal change management to be ready to the IoT load.

The Internet of Things is defined by IoT European Research Cluster (IERC) as a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes and virtual personalities, use intelligent interfaces, and are seamlessly integrated into the information network [1].

Many emergent IoT applications will be delivered on-demand through a cloud environment. Thereby, the need to employ new adequate datacenter technologies arises. They would offer high productivity, reliability and elasticity in a scalable fashion.

A significant scientific effort in the field of IoT is devoted to the Smart Environments class systems, such as the Smart Home, Smart City, Smart Office, Smart Energy & Fuel, Smart Health, environment monitoring and others. IoT evolution in this direction is very intense [2].

The most intensively developing ecosystem is Machine-to-Machine (M2M) of which services process huge amounts of data obtained from sensors [3]. Data from sensors needs to be transferred to the respective applications in compliance with security policies and priorities. In this case, cloud IoT services use stored data to perform analysis for decision-making to improve business performance. By 2020, the number of IoT objects worldwide could reach 212 billion. And by 2022, the traffic M2M services could reach 45% of all traffic on the Internet [4].

External impacts from IoT are creating new demands to the data center. By 2020, Gartner predicts that 25 billion devices will be connected to the Internet, creating greater external demand for storage and communication with the data center.

In its documents, the European Telecommunications Standards Institute (ETSI) focuses on the M2M concept instead of using the word “Internet of Things”. ETSI defines M2M as communication between two or more entities that do not necessarily need any direct human intervention. M2M services intend to automate decision and communication processes [5].

According to Forrester [6], a smart environment uses information and communication technologies to make the critical infrastructure components and services of a city administration, education, healthcare, public safety, real estate, transportation and utilities more aware, interactive and efficient.

Significant business decisions have been taken by industry leaders like IBM, Intel, Microsoft, Cisco, Google, Apple and Samsung to develop technologies and services for the IoT landscape. The EU has also invested in supporting research and innovation in the field of IoT in different service sectors and application groups.

Telecom operators also consider that IoT and M2M are becoming a core business focus. A significant growth of connected devices and sensors is reported in their networks. Manufacturers of wearable devices anticipate a full new business segment towards a wider adoption of the IoT.

2. The problem

The IoT is considered as a widely distributed and locally intelligent network of smart objects. The IoT enables many new enhancements to fundamental services, such as city administration, education, healthcare, public safety, real estate, transportation and other sectors. Business success greatly depends on the IT-service quality. It makes the scientific and applied problem of development IoT infrastructure management concept important.

The increase in business demand for IT services in the IoT area and the emergence of new services lead to the necessity of developing and implementing new approaches to the IT infrastructure management.

Modern IT infrastructure management systems are complex and are integrating solutions from different manufacturers. The increasing complexity of IT management is accompanied by the growth in the cost of operations. The main task of IoT infrastructure management is to maintain a coordinated level of IT services with the rational use of IT infrastructure resources in terms of virtualization, clustering, distribution and increasing the amount of user requests.

Thus, the authors' objectives in this paper are: 1) to analyze the use of Cloud in the IoT applications, 2) to develop a system model for Microcloud-based IoT infrastructure, 3) to develop an approach to service quality management in the IoT systems, and 4) to define coordination principles in Microcloud-based IoT management system.

3. System model for Microcloud-based IoT

Many city scale or region IoT systems may encompass part of the country, the whole country or several countries. It is recommended that such scale IoT systems are built on the basis of Cloud in conjunction with Microcloud concepts. This kind of city-scale systems include, for example, parking automation systems, road traffic monitoring systems, traffic management, security surveillance cameras, public transport management, smart public transport, etc. In this case, Micro cloud may cover an administrative district of the city or part of the territory of an administrative district when one administrative area will be covered by several Micro clouds. To solve such tasks for large-scale IoT systems, the authors propose Microcloud-based IoT architecture.

In addition to the vertical interaction between Cloud and Micro cloud, horizontal interaction Micro cloud – Micro cloud is proposed in the following cases:

- When it is necessary to provide low latency.
- When local Micro cloud data are used by another Micro cloud and in case of local control.
- Micro cloud mobility.

– A very large number of end nodes (sensors) to reduce global traffic.
– When one uses distributed real-time applications that require data sharing and management of multiple Micro clouds.

Generalized system model of the proposed Microcloud-based IoT architecture is shown in Fig. 1.

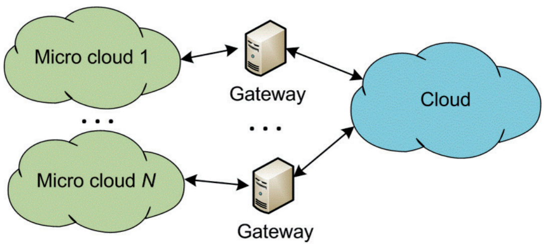

Fig. 1. Generalized system model of the proposed Microcloud-based IoT architecture

Possible ways of communication and information exchange between Cloud and *N* Micro clouds are shown in Fig. 2.

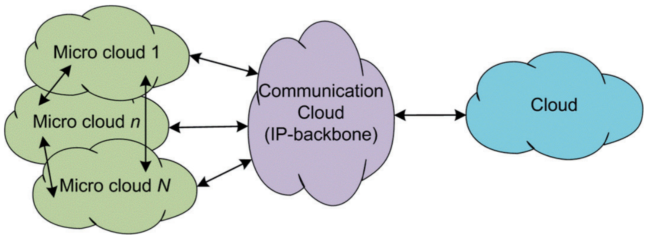

Fig. 2. Possible ways of communication and information exchange between Cloud and Micro clouds in the proposed architecture

The interaction of the sensors and actuators within the *n*-th Micro cloud service *Mn*, $n = \overline{1, N}$, where *N* is the amount of Micro clouds in an IoT system, with the possibility of Cloud and other Micro clouds to be carried out through the IP-backbone or using direct data exchange between Micro clouds and within Micro clouds. A direct interaction between Micro clouds and within Micro clouds can be carried out using protocols Wi-Fi, 3G, 4G, LTE, IEEE 802.15.4, Sensor-Net, WiMAX, Ultra-Wide Band (UWB), ZigBee, Bluetooth, 6LoWPAN.

4. A two-tier IoT management system model

Problem solving in IoT systems based on the Microcloud architecture requires computing and storage resources. Micro cloud and Cloud both have these resources. Micro cloud resources usually are limited, so there is a problem of the development of task allocation methods between the Micro cloud and Cloud for the efficient resources use.

To solve such problems in the management of corporate IT infrastructures in the [7] decomposing-compensation approach is proposed. Decomposing-compensation approach can be adapted for solving resource allocation problems in Microcloud-based IoT system as follows.

To ensure the profitability of companies operating in the field of IoT, it is essential for them to receive the set $\mathfrak{S} = \{s_i\}, \ i = \overline{1, K}$ IoT necessary services of the highest quality $\mathfrak{Q}$ and at the minimum cost, $\mathfrak{C}$.

Service Level Management in the Microcloud-based IoT system is proposed to be carried out by integrated interaction of three processes: the service level coordination, resource planning level and service level management level.

Due to the fact that the current research on control theory is focused on the multi-site fact, distribution, large dimension problems, there is a need to highlight a special class of multi-site distributed management systems, which include control systems for Microcloud-based IoT architecture. One of the major issues addressed in the design and operation of such hierarchical control systems, in addition to the development of architecture, is the decision-making problem.

The complexity of decision-making process in hierarchical control systems is caused by the fact that decisions are made on most levels of management hierarchy, as well as the time for decision-making being limited. In [8], it is proposed to consider such systems as two-tier management systems with a coordinator [9].

The basis for singling out two levels in the control system is that the service level management system in the Microcloud-based IoT architecture functions in different modes in case of uncertainty, incomplete and unreliable information, the presence of risk factors, different conflicting criteria and objectives of management subsystems.

It is very difficult to achieve the optimum operation of the system, built on the Microcloud-based IoT architecture, with such control systems. Control systems in Microcloud-based IoT architecture are necessary for improving the quality metrics of IoT system. In such cases, the development of two-level systems with the coordinator are proposed [8, 9], when the coordinator coordinates its own decisions and management actions of subsystems to improve Microcloud-based IoT system as a whole in terms of quality of services provided.

At the same, time coordinator decisions should be directed at improving the global quality function of services and decision-making is carried out under uncertainty.

Fig. 3 shows the structure of the control system, which manages service level in the Micro cloud-based IoT architecture in the form of a two-tier system with a coordinator [8, 9].

The location of control subsystems (CS) shows the hierarchical structure of the control system model. The model consists of the Coordinator as an upstream control subsystem (CS_0) and $N + 1$ downstream control subsystems ($CS_1, ..., CS_N, CS_C$), which directly control the process P that occurs in Micro cloud-based IoT infrastructure. Vertical interaction between CSs is as follows.

Commands, signals, feedback or interventions (inputs) $\gamma_1, ..., \gamma_N, \gamma_C$, transmitted from the CS_0 to $CS_1, ..., CS_N, CS_C$ are coordinating ones. The commands or impacts (inputs) $(u_1, ..., u_N, u_C)$ from the $CS_1, ..., CS_N$, CS_C to process P are controlling ones. Feedback signals or data signals $v_1, ..., v_N, v_C$ and $\beta_1, ..., \beta_N, \beta_C$ come from bottom to top. Two-level control system can be described by the terminal variables (inputs and outputs). In this case, the CSs are described as functional subsystems, the outputs of which are uniquely determined by the inputs [9].

Process P can be described as a controlled subsystem, which is affected by the control signals u from the $CS_1,...,CS_N,CS_C$, $u \in U$, U – the set of control actions; the incoming input signals z, $z \in Z$, that represent user's requests; the signals ξ, $\xi \in \Xi$, which are the disturbing influences.

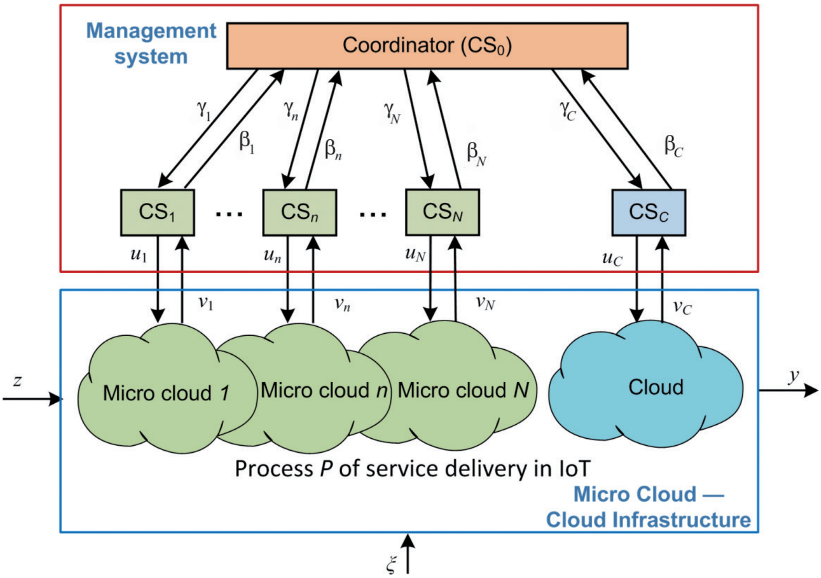

Fig. 3. Two-tier control system model with the coordinator to provide service delivery management in the Micro cloud-based IoT architecture

Disturbing influences Ξ are the faults in the Microcloud-based IoT infrastructure, functional resource failures, requests to other Microcloud-based IoT systems sharing joint resources, or an increase of monitoring data volume that require processing and other reasons. Requests to other IoT systems are considered to be disturbing influence towards the considered IoT system that makes it difficult to achieve management goals.

The output of the process P is y, $y \in Y$, where Y – the set of the outputs of process P, which are considered as IoT system responses to users' queries or results of IoT system operations.

Process P can be represented as a mapping based on the Cartesian product:

$$P : U \times Z \times \Xi \to Y \tag{1}$$

The set of control signals U influencing the process P by $CS_1,...,CS_N,CS_C$, are represented as a Cartesian product of $N + 1$ sets [9].

$$U = U_1 \times U_2 \times ... \times U_N \times U_C. \tag{2}$$

In this case, each control subsystem of $CS_1,...,CS_N,CS_C$, has the authority to select individual component $u_1, \dots, u_N, u_C$ of control action u from the corresponding set $U_1, \dots U_N$ or U_C to have a direct impact on the process P.

Two signals come at the inputs of each g-th management subsystem $CS_1,...,CS_N,CS_C$: a coordinating signal $\{\gamma_1,...,\gamma_N,\gamma_C\} \in \Gamma$ from CS_0 and feedback $v_1,\dots,v_N, v_C$ as a monitoring data. The control output of each $CS_1,...,CS_N,CS_C$, is the impact chosen by $CS_1,...,CS_N$, CS_C from the corresponding set of $U_1, \dots U_N$ or U_C. Assume that each of $CS_1,...,CS_N,CS_C$, implements corresponding mapping $C_1,\dots,C_N,C_C$, such that:

$$C_1 : \Gamma \times V_1 \to U_1,...,C_N : \Gamma \times V_N \to U_N, C_C : \Gamma \times V_C \to U_C, \tag{3}$$

where each component of $V_1, \dots, V_N, V_C$ is set of monitoring data $v_1, \dots, v_N$, or v_C, coming into the control system from the Microcloud-based infrastructure, and $v_1 \in V_1,...,v_N \in V_N, v_C \in V_C$. Monitoring data $v_1, \dots, v_N, v_C$ are the feedback signals for the local control loop, which is based on $CS_1,...,CS_N,CS_C$.

The feedback signals $v_1, \dots, v_N, v_C$, as an input to the $CS_1,...,CS_N,CS_C$ are obtained by monitoring the Microcloud-based infrastructure. They contain information regarding the flow of process P. Naturally, these signals are functionally dependent on the control signals u, input signals z, disturbing influences ξ and outputs y. This relationship can be represented by a set of mappings [9]:

$$f_1 : U \times Z \times \Xi \times Y \to V_1,..., f_N : U \times Z \times \Xi \times Y \to V_N, f_C : U \times Z \times \Xi \times Y \to V_C. \tag{4}$$

Management subsystem CS_0 is a coordinator. It generates coordinate signals $\gamma_1,...,\gamma_N,\gamma_C \in \Gamma$, and each signal $\gamma_1,...,\gamma_N,\gamma_C \in \Gamma$, from a corresponding output of the CS_0 is only coming to the input of a separate downstream control subsystem $CS_1,...,CS_N,CS_C$. The coordinator CS_0 produces a signal based on an analysis of information coming to its input from the $CS_1,...,CS_N,CS_C$. The coordinator signal is representing the feedback signals and generalized information about the status and functioning of the Microcloud-based infrastructure. In this case, we can assume that C_0 mapping is implemented in coordinator such that:

$$C_0 : \mathrm{B} \to \Gamma, \tag{5}$$

where:

B – a set of information signals β, implementing feedback.

Moreover, $\beta = (\beta_1,...,\beta_N,\beta_C)$ is a set of feedback signals $\beta_1,...,\beta_N,\beta_C$ coming into the coordinator CS_0 from $CS_1,...,CS_N,CS_C$ subsystems. Similarly to (4), the feedback signal β incoming to CS_0, carries information about the status of all subsystems downstream, so it is determined by mapping:

$$f_0 : \Gamma \times V \times U \to \mathrm{B}, \tag{6}$$

where:

$V = V_1 \times ... \times V_n$. Thus, B is a function of coordinating signals $\gamma_1,...,\gamma_N,\gamma_C$, feedback signals $\nu = (\nu_1,...,\nu_N,\nu_C)$ incoming to $CS_1,...,CS_N,CS_C$, and control actions $u = (u_1,...,u_N,u_C)$.

In the model in Fig. 3, the interaction between subsystems $CS_1,...,CS_N,CS_C$, is not shown explicitly, as well as direct impact CS_0 on the Microcloud-based infrastructure functioning. Also, the process of receiving direct feedback signals by coordinator CS_0 from the Microcloud-based infrastructure elements is not shown, but such processes take place in real control systems.

According to [9] coordination is the process of impact on the $CS_1,...,CS_N,CS_C$, management subsystems, which forces them to operate consistently, subordinating the action of each of the $CS_1,...,CS_N,CS_C$, to one general policy aimed at the achievement of the global system objectives, despite the fact that this objective may conflict with the objectives of local subsystems. Coordination is carried by CS_0, and the coordinator has to overcome the contradiction between the objectives of local subsystems $CS_1,...,CS_N,CS_C$.

The success of the coordinator activity on coordinating $CS_1,...,CS_N,CS_C$ can be measured by how successfully the global goal of Microcloud-based infrastructure management is achieved. Achieving the goal by the coordinator can be regarded as a solution to the problem, which can be formalized as the decision-making problem and lies in the assessment of coordination effectiveness. As this task is determined with respect to all subsystems, including process *P*, then it is called a global problem to be solved [9].

For the two-level control systems, two conditions must be met: to be coordinated according to the problem to be solved by CS_0, and to be coordinated in relation to the global problem [9]. The first means that CS_0 signals have a coordinating effect on the tasks to be undertaken by $CS_1,...,CS_N,CS_C$, and the second shows that the coordinator is able to influence the $CS_1,...,CS_N,CS_C$ so that their combined impact on the process *P*, executed by IoT system, is aimed at solving a global problem.

The successful operation of a management system based on a two-level model can be achieved only when the subsystems' objectives are coordinated with each other and aligned with the global objective of the system [8, 9].

In a two-level system, there are three types of objectives:

– A global objective.
– Coordinator CS_0 objective.
– Objectives of $CS_1,...,CS_N,CS_C$.

The need of objectives compatibility arises from the following specifics.

Generally, the process of *P* is directly affected only by $CS_1,...,CS_N,CS_C$, so the global objective can only be achieved indirectly through the actions of $CS_1,...,CS_N,CS_C$, which must be coordinated with respect to the global objective, as well as with respect to coordinator objective.

The global objective is to improve the efficiency of business processes and this objective goes beyond the immediate activity of the two-level system shown in Fig.3. And none of the subsystems $CS_1,...,CS_N,CS_C$ are focused on the achievement of the global objective or on solution of the global problem. A global problem can be solved only by joint action of all control subsystems $CS_1,...,CS_N,CS_C$.

The global objective. Given the fact that the Microcloud-based infrastructures are created to improve the functioning of IoT systems, the global objective of a management system is to provide the highest quality $\mathfrak{Q}$ of services of IoT system with minimal cost $\mathfrak{C}$. Thus, the aim of process management in accordance with ITSM and ISO is the constant improvement of IT services level, that can be formally written as $\max \mathfrak{Q}$.

The maximum quality of service in the Microcloud-based infrastructures will be achieved in the case when:

$$\max \mathfrak{Q} \Leftrightarrow \max Q_i, \forall i = \overline{1,K} \Leftrightarrow \max q_{ki}, \forall i = \overline{1,K}, \forall k = \overline{1,L_i} \quad (7)$$

where:

$Q_i, i = \overline{1,K}$ – the quality of the *i*-th service,

$q_{ki}, k = \overline{1,L_i}$ – the value of *k*-th quality indicator of *i*-th service provided by IoT system.

To achieve the goal of process management, it is necessary to continuously increase the Microcloud-based infrastructure resources, which is unacceptable, especially from the economic point of view. On the other hand, increase of the economic efficiency of doing business requires a cost reduction to the Microcloud-based infrastructure, aimed at achieving $\min \mathfrak{C}$. Maintenance of the service quality at this level is the main task of coordinator.

The objective of the coordinator. The objective of the coordinator is to maintain the quality of services $\mathfrak{Q}$ to an agreed level with a minimum $\mathfrak{C}$ of the involved resources. The purpose of the coordinator can be formalized as follows:

$$\mathfrak{Q} = \text{const}\Big|_{\min \mathfrak{C}} . \quad (8)$$

The expression means that the coordinator of all the possible procedures will select those which require minimal implementation cost. The requirement of maintaining the agreed level of services is applied to all services and individual service quality indicators:

$$\mathfrak{Q} = \text{const} \Leftrightarrow Q_i = \text{const}, \forall i = \overline{1,K} \Leftrightarrow q_{ki} = \text{const}, \forall k = \overline{1,L_i}, \forall i = \overline{1,K} . \quad (9)$$

It is necessary to stipulate the following fact. The main way to improve the quality of the *i*-th service $i = \overline{1,K}$, is the allocation of additional resources to the applications that support the *i*-th service. When the level of *i*-th service exceeds the target value, the reduction in resources allocated to the appropriate applications as required by the criterion $\min \mathfrak{C}$ is produced. At the same time, the last server providing the *i*-th service cannot be turned off, despite the fact that the quality of the service is still higher than the desired since it will lead to a complete cessation of service. Thus, there will always be some fixed minimum cost $\mathfrak{C}$, and then a further cost reduction will be impossible.

The local objectives. The objective of the local management is to maintain preset values of functioning parameters of the Microcloud-based infrastructure at minimum cost. The model of control system shown in Fig. 3, control subsystems $CS_1,...,CS_N,CS_C$ may have their own distinct operation objectives.

5. Coordination Principle definition

Implementation of coordinatibility and compatibility requirements are the limitations in determining the strategies that can guide the coordinator. Proposed in [9], the principles of coordination, based on the postulate of compatibility, cannot be used in the management system of Microcloud-based infrastructure, because they assume obtaining and using accurate prediction of parameters of the process *P*, or require knowledge of functions or the analytical expressions for the solution of the coordination problem. For a coordination problem to be solved, it is necessary to synthesis the coordinator and determine the methods, procedures or coordination algorithms after decomposition of the global objective.

Rewrite the objective of coordinator in the following way:

$$\min \Delta Q_i = \min(Q_i - Q_i^*), \forall i = \overline{1,K} \Leftrightarrow \min \Delta q_{ki} = \min(q_{ki} - q_{ki}^*), \forall k = \overline{1,L_i}, \forall i = \overline{1,K}, \qquad (10)$$

where:

Q_i, Q_i^* – the desired and the actual values of the *i*-th service quality indicator;

q_{ki}, q_{ki}^* – the desired and actual values of the *i*-th service quality indicator.

The actual quality is considered worse than required for $Q_i > Q_i^*$, and respectively, for $q_{ki} > q_{ki}^*$.

The inputs of the process *P* receive control and disturbing influences, and the management system's task is to choose such control that is counteracting to disturbing influences. Based on , the coordinator should compare current values of services quality indicators $q_{ki}^*, k = \overline{1,L_i}, i = \overline{1,K}$ provided to users by the process *P*, with the target (desired) values $q_{ki}, k = \overline{1,L_i}, i = \overline{1,K}$ and work out the coordination signals that minimize the deviation.

When control is aimed at maintaining the agreed service level, it is natural to use the principle of control by the deviation [8]. Outputs of the process *P* go through appropriate transformation to bring the metrics together to determine the values $q_{ki}, k = \overline{1,L_i}, i = \overline{1,K}$. In this case, the outputs of the process *P* by feedback circuit come to the coordinator, and are compared with target values. On the basis of the deviation $\Delta q_{ki}, k = \overline{1,L_i}, i = \overline{1,K}$, coordinating signals are produced for $CS_1,...,CS_N,CS_C$.

Main disturbing influences can be measured by the management system. These disturbing influences are the fluctuating number of services users $\hat{a} = \{a_l, l = \overline{1,I}\}$, fault impact on the quality of service, congestion of communication channels, and others. This allows to use the control principle based on a disturbing influence together with control based on deviation and to implement in a management system a combined control. At that point, control based on deviation has more weight. Fig. 4 shows the result of coordinator decomposition when coordinator implements a combined service level management principle.

The coordinator in Fig. 4 contains negative feedback loop and circuits to compensate disturbing influences $\xi \in \Xi$. The compensation circuit evaluates the main disturbing influences, which are taken into account when choosing a correction signal.

Global objective of Microcloud-based infrastructure management can change that arises for the coordinator by changes of application $\{A_l\}$ priorities *Pr*, ensuring the provision of the set $\mathfrak{S} = \{s_i\}$, $i = \overline{1,K}$, of the IoT services and targeted values $Q_i, i = \overline{1,K}$ of services level. In this case, the expression takes the form:

$$C_0 : Pr \times Q_i \times \mathrm{B} \times V \times \Xi \rightarrow \Gamma, i = \overline{1, K}. \qquad (11)$$

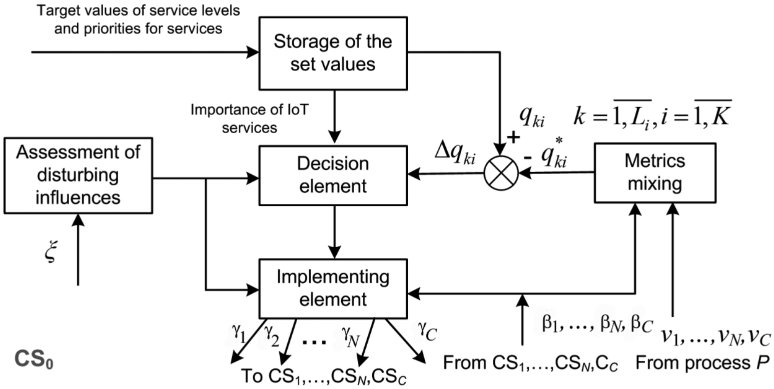

Fig. 4. Coordinator structure, coordinator is using a feedback and taking into account the disturbing influences

Once the principle of management is determined, it is necessary to determine the strategy and the rules of coordinator and conditions of policies or rules application.

Selection of coordinating impact is determined by the system:

$$< Pr, \Delta\hat{q}, \mathrm{B}, V, \Xi, \mathfrak{N} >, \qquad (12)$$

where:

$\Delta\hat{q}$ – the vector of deviations,

$\mathfrak{N}$ – situational uncertainty.

Let us analyze the system. Application priorities *Pr* are set by the customer of the IoT system, and take values from the set {1, 2, …, Pr_m}, where Pr_m is the maximum value of the priority. In Microcloud-based infrastructure and IoT systems operation, the priorities of applications *Pr* vary, tracking importance changes in business processes or in processes utilizing the IoT system.

In order to characterize the degree of deviation values of vector $\Delta\hat{q} = (\Delta q_{1,1}, \dots, \Delta q_{k,i}, \dots, \Delta q_{M_K, K})$ from the target values, we introduce a function $w(\Delta q_{ki})$, $\forall k = \overline{1, M_i}, \forall i = \overline{1, K}$, that takes values on the interval [–1, 1] and determines the degree of proximity of the actual quality level to the target values:

$$w(\Delta q_{k,i}) = (q_{ki} - \overset{*}{q}_{ki}) / q_{\text{кр}_{ki}}, \qquad (13)$$

where:

$q_{\text{кр}_{k,i}}$ – the critical value of quality index of the *i*-th service, in which quality is considered to be unsatisfactory.

And when $w(\Delta q_{k,i}) \in (0,1]$ the actual value of the quality index of the *i*-th service is better than required and when $w(\Delta q_{k,i}) \in [-1, 0)$ service quality is worse than previously agreed.

Of all the types of uncertainties typical for Microcloud-based infrastructure, the most is situational uncertainty $\mathfrak{N}$, characterized by the unpredictable actions of users, unpredictable emergency situations, the difficulty of determining the resource responses on a combination of influencing factors. This raises the problem of generating the coordinating $\gamma = (\gamma_1,...,\gamma_n)$ and control $u = (u_1,...,u_n)$ actions considering feedback signals $v = (v_1,...,v_n)$ and $\beta = (\beta_1,...,\beta_n)$ under the influence of disturbances $\xi \in \Xi$ and under conditions of uncertainty $\mathfrak{N}$.

As it is not possible to determine an appropriate mapping analytically, the only way out is to use iterative coordination procedures [8, 9], involving all the processes that implement the management of service level. The use of an iterative procedure allows to generate acceptable coordinating impact due to the monotony of the functions of quality indicators' dependency on resource values, as well as the monotony of influence of the situational uncertainty $\mathfrak{N}$ on the service level. Therefore, to control the quality of services provided by IoT system in Microcloud-based infrastructure for uncertainty disclosure, it is advisable to use iterative procedures for the management.

The main function of the coordinator is to agree the activities of $CS_1,...,CS_N,CS_C$ while generating their own solutions so as to increase the overall impact of their joint actions. Therefore, the decisions taken by the coordinator, influence the choice of coordination actions, not control actions [8]. To select coordinating actions, it is necessary to determine the principle of coordination.

In the management system, the coordinating impact indicates which of the $CS_1,...,CS_N$, CS_C is preferred when restoring the quality of services and what methods should be used. An example of possible actions $CS_1,...,CS_N,CS_C$ is shown in Fig. 5.

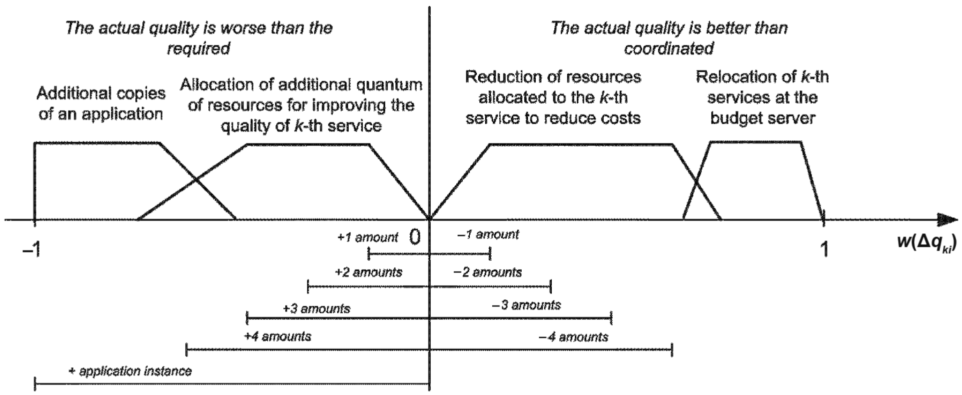

Fig. 5. An example of action selection $CS_1,...,CS_N,CS_C$, depending on the value of the function $w(\Delta q_{ki})$

For example, when communication channels are overloaded, allocation of additional computing resources for applications from set $\{A_l\}$ will not restore the level of service quality. Therefore, coordinator CS_0 informs appropriate subsystem $CS_1,...,CS_N,CS_C$, responsible for network flows management, the need to limit outgoing traffic from applications from $\{A_l\}$ that have the lowest priority. Such coordination may be implemented, for example, by using a coordinating principle based on productional system.

The use of a coordinating principle based on a productional system is justified in cases where the goal is to improve the quality of services, rather than to achieve optimal performance operation of the Microcloud-based infrastructure under condition with lack of information about the factors that affect the results of coordination and control actions.

Mappings can have a very complex form, and for the system , it is impossible to obtain analytically the resulting relationship between the coordinating actions $\gamma = (\gamma_1,...,\gamma_n)$, control actions $u = (u_1,...,u_n)$ and process P output. In this case, the software control can be used.

The main coordination procedures are the use of iterative procedures to improve the coordinating signals based on the analysis results of the coordination or the use of feedback for the correction of coordinating signal [8]. It is advisable to use both types of procedures. In both cases, to determine the error signal in assessing the impact, it is necessary to make reduction of metrics measured at process P to metrics coordinator operates.

It should be noted that the coordinator is used for automatic control of service level, and for the automated management the coordinator performs the role of decision support system.

6. Conclusions

In this paper, the authors provide an overview of the vision, architecture, and benefits of proposed IoT infrastructure management system based on the Microcloud concept.

The authors have analyzed the use of Cloud in the IoT applications, developed a system model for Microcloud-based city scale or region IoT applications, proposed a new approach to service quality management in the IoT systems based on decomposition-compensation method, as well as defined coordination principles in Microcloud-based IoT management system.

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