A condition of reliability improvement of the system based on the fog-computing concept

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Abstract. In this paper, the effect of the fog-computing concept, applied to the information and control systems, is considered. A special condition of the fog-computing application expediency has been developed. It has been proved that the system reliability improvement is reachable using the fog-computing concept, if the workload shifted to the fog nodes does not exceed the workload conducted by the transit data transmission. In this case the application of the fog-computing concept is expedient and useful. Some simulations, which illustrate the condition proposed, were conducted in this paper.

1. Introduction
The fog computing concept, formulated and presented in 2012 [1], is considered as an extension of a cloud concept. As far as the paramount idea of the fog-computing is to put the data preprocessing to the data sources neighbourhood, the expected advantages of this computing concept are as follows [2,3]:
- reduction of the data processing and the system response time;
- offloading of the network infrastructure.

The obvious drawback of the computational load shift is still that the fog-layer devices get additional load. Considering the assumption that the devices in the fog-layer are less productive than the ones in the cloud, the load shifted can be more tangible for those devices in comparison with the same load in the cloud.

The fog computing concept is quite new, but intensively explored by scientists, including questions of workload distribution between cloud and the fog, fog and the edge of the network, methods and algorithms of the workload location through the devices. However, the question of how fog computing affects the reliability of the devices is not observed properly, except, to the best of our knowledge, in the [4-8].

In the current paper, we estimate the expediency of the application of the fog-computing concept to the stand-alone industrial information and control systems. Such systems are used in robotized production processes, in robotic complexes, in gas and oil refinery and so on [9-12]. Very frequently the systems mentioned are distributed geographically, and sensors and actuators are a complex problem for maintenance.

The usage of the fog computing concept, as was mentioned above, can improve the system latency...
and reduce the network load. At the same time the question of its effect on the reliability of the devices is not solved, so, it is in the focus of this paper.

2. The common structure of the information and control system and the fog-computing application

Let us consider the information and control system as a set of control tasks which are distributed through the set of computational nodes. The raw data come from sensors and have to be processed by a set of control tasks. The classical systems use the cloud architecture, i.e. when the computational tasks are performed in the “cloud”, which is the set of computational nodes, which constitute the computational environment of the information and control system. The “edge” devices are sensors or other user devices, and the “fog” layer consists of controllers and communication devices, e.g., commutators, switches, as is shown in Figure 1.

![Figure 1. Cloud architecture of the information and control system.](image)

The computational tasks, which implement the functionality of the information and control system, can also be considered as a directed graph. Each subtask has its own computational complexity, transmits data to other subtasks and, for real-time systems, has strict time limits for completion. A considerable part of this graph can be located in the fog layer, as is shown in Figure 2.

![Figure 2. The workload shift to the fog layer.](image)

Comparing these two configurations, the following particularity is noticeable: while all computational tasks are performed in “cloud”, the one type of workload, which is on the fog-layer devices, is the transit workload, which is generated when the device performs some operations to transmit some data through itself. When some computational tasks are on fog-nodes, the transitional load is reduced to some degree, but is substituted with the workload, which is generated by the need to
perform the computational tasks. Besides, assuming the cloud devices to be of a high performance and the fog devices to be less productive, it is very important to choose such task distribution in order not to worsen the reliability of the fog-device.

3. A condition for the system reliability improvement

Let us consider the situation when some computational tasks are relocated from the device in the cloud layer to the fog. Obviously, the reliability of that cloud device improves; the transit load of those devices, which receive the computational tasks, degrades while the relocated tasks generate the additional node workload. But, in case the cloud workload decreases and the general fog-node workload decreases too, the overall system reliability improves assuming the number of nodes is constant.

Theorem: the non-decreasing of the system reliability function under the condition of the constant node quantity is achievable provided that a certain inequality (1) corresponds to each node:

\[
\sum_{i=1}^{k} W_i^f A_s^f + \sum_{j=1}^{l} W_j^r A_t^f + A_c^f \leq A_{tr}^f (W_{tr}^c - W_{tr}^f) \tag{1}
\]

where \(k\) - the number of tasks, which are located on the current node and send data to other tasks on other nodes;

\(W_i^f\) - the data value to be sent by the task \(i\), which is located on the node;

\(A_s^f\) - operations per byte of data sent;

\(l\) - the number of tasks, which are located on the node and receive data from other tasks on other nodes;

\(W_j^r\) - the data value to be received by the task \(j\), which is located on the node;

\(A_r^f\) - operations per byte of data received;

\(A_t^f\) - task \(t\) of computational complexity;

\(A_{tr}^f\) - operations per byte of the transit data;

\(W_{tr}^c\) - the transit data value in case of cloud concept implementation;

\(W_{tr}^f\) - the transit data value in case of fog concept implementation.

We consider the network of the tree-like topology. For the further estimations we consider the brunch of the tree as a route of data transmission from the edge to the cloud (Figure 3).

![Figure 3. The route of the data transmission.](image)
Also let us assume that the initial computational load location proceeds according to the cloud concept, i.e. the computational workload of the data processing tasks is located in the cloud, the performance of which is higher than the performance of fog-layer devices.

In this case the fog-layer devices are busy with the transit workload, and every fog device has the computational load $A_{tr}^f W_{tr}^c$. The variable $W_{tr}^c$ is a sum of the transmitted data value which is sent from the edge to the cloud.

With the avoidance of the cloud architecture, the workload shift to the fog layer takes place. In two general cases the following is going on:

- the fog device functions as a transit node as it was mentioned earlier, so its workload consists in $W_{tr}^c A_{tr}^f$;
- if a part of tasks is shifted to the fog layer, the fog node can get the following workload:

$$\sum_{i=1}^{k} W_{is}^f A_{s}^f + \sum_{j=1}^{l} W_{jr}^f A_{r}^f + A_{tr}^f W_{tr}^c.$$ 

It must be mentioned that for a non-decreasing reliability function of the device, the following equation must be fair:

$$P_i^f(T) \geq P_i^c(T). \quad (2)$$

So, the reliability of a node under the fog-concept conditions must be not less than the one under the cloud conditions, where T is a fixed time moment.

Then, with the decrease of the cloud workload and the decrease of the fog node workload, the overall system reliability function improves.

Let us consider the following equations, as it was proposed in [13].

$$p_i^f(T) = e^{-\lambda T} \quad (3)$$

$$\lambda = \lambda_0 \cdot 2^{kD/10} \quad (4)$$

where $D$ – the device workload.

$$D^c = \frac{W_{tr}^c A_{tr}^f}{P_{node^f session}} \quad (5)$$

where $P_{node}$ - a node performance;

$t_{session}$ - a time of tasks set completion.

We can consider the node load under the conditions of the fog computing concept application:

$$D^f = \frac{\sum_{i=1}^{k} W_{is}^f A_{s}^f + \sum_{j=1}^{l} W_{jr}^f A_{r}^f + A_{tr}^f W_{tr}^c}{P_{node^f session}}. \quad (6)$$

So, according to eq.(2,3,4), the following is fair:

$$p_i^f(T) \geq P_i^c(T)$$

$$\sum_{i=1}^{k} W_{is}^f A_{s}^f + \sum_{j=1}^{l} W_{jr}^f A_{r}^f + A_{tr}^f W_{tr}^c \leq A_{tr}^f W_{tr}^c.$$ 

The resulting equation is as follows:

$$\sum_{i=1}^{k} W_{is}^f A_{s}^f + \sum_{j=1}^{l} W_{jr}^f A_{r}^f + A_{tr}^f W_{tr}^c \leq A_{tr}^f (W_{tr}^c - W_{tr}^f), \text{ Q.E.D.} \quad (7)$$
4. Some estimations and simulation results
To estimate the tendencies of the fog-computing application expediency, we conduct some simulations based on equation, obtained in the previous section. We consider the parameters for the comparison of the left and right parts of equation (1). Under the conditions of the variable transit workload and the computational workload being equal to 100 modelling units (m.u), the following graphs are presented.

![Variable transit workload](image)

**Figure 4.** Variable transit workload.

One can see that only if the cloud transit workload is higher than 600 m.u., and the workload to be distributed is equal to 100 m.u. for all fog nodes, the reliability improvement can be reached. With the lower transitional workload it is pointless to apply the fog computing concept in terms of reliability. Therefore, under the current modelling conditions, the removal of the transit workload of more than 600 m.u. for all nodes allows one to improve the system reliability.

Another example illustrates the inexpediency of the fog computing application.

![Inexpediency of the fog-computing application](image)

**Figure 5.** The inexpediency of the fog-computing application (transit workload is equal to 500 m.u).

Here the transit workload is equal to 500 m.u., and the workload shifted to the fog grows from 50 to 950 computational complexity m.u. As is seen there is no situation when the reliability can be improved.
However, there can be a situation when the transit workload is equal to 610 m.u., and the workload in the fog varies from 50 to 905 computational complexity m.u. The graphs will be as is shown in the figure below:

![Graph](image)

**Figure 6.** The illustration of the variable computational complexity shifted to the fog.

In Figure 6 one can see that the graph of the left part of the equation (1) lies under the graph of the right part of the equation. So, when the transit workload is 610 m.u. and the workload, which is shifted to the fog, grows, the reliability improvement is possible if the shifted workload is limited by the value of 450.

5. **Conclusion**

Fog computing is quite useful in a variety of aspects of system functioning:
- it improves the time of information processing;
- it reduces the time of system response;
- it decreases the network workload.

However, the question of dependability of such fog-oriented systems is quite poorly observed, though dependability itself and reliability in particular are an important issue in a wide area of robotic complexes and unmanned production systems.

Dealing with the reliability, it is useful to estimate the expediency and the benefits of the fog computing concept implementation. The contemporary and widely used models still do not consider an important parameter of the workload, generated by the transit data transmission. The paramount idea of this paper is that when we shift the computational workload to the fog devices, we eliminate the transit workload partially, but increase the workload conducted by the computational tasks.

Therefore, in this paper, a condition of the system reliability growth is formulated and proved. In general, the reliability improvement is reachable by the fog-computing concept application, if the workload shifted to the fog nodes does not exceed the workload conducted by the transit data transmission. If all nodes satisfy this condition, the application of the fog-computing concept is expedient and useful.

In addition, some simulations, illustrating the condition proposed, were conducted.

6. **Acknowledgments**

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