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END-TO-END CONTROL AND OPTIMIZATION IN INFORMATION AND CALCULATING NETWORKS

Introduction

An aid of the paper is research and development of the system of interaction and distribution of resources in complex information and calculating systems. Particularly, we consider the problem of minimisation delay of delivery data in distributed network systems with software configuration, which is realized on one central point of control (so called software-defined networks, SDN).

Definition of the issue

The theory of optimal control and optimisation, in addition to the classical control theory, has reached a high level of maturity [1]. So we can say about the theory of resource interaction in distributed information systems [2]. However, the problem of optimally controlling such systems can, in principle, be solved only under one necessary condition: when all pertinent information on the structures, parameter values, and/or nature of random disturbances affecting the system performances is available.

To synthesize optimal control systems, the necessary information for the problems, e.g., sufficient statistics for underlying parameter θ precisely (we suppose the conditional probability distribution of the data X, given the statistic $t = T(X)$, does not depend on the parameter θ). But the task of optimising the time of data delivery in modern distributed systems with remotely spaced elements is stochastic by definition. The reasons for this are as follows.

1. There is no complete information about the network status.

2. There are sudden failures, which can neither be predicted nor prevented.

3. There is no information about changing the computing and network load, in particular, the computational complexity of tasks that are subject to solution at times unknown in advance.

4. Other factors that cannot be foreseen or excluded.

It is clear that actually, the “perfect information” situation is never true, and one needs a theory of control which allows acceptable systems to be synthesized even when one or more pieces of key information required by the current optimal control theory are lacking. So we have to go from deterministic problem or from stochastic problem with parametric prior uncertainty to so-called “pure” stochastic problem [1; 3]. Let's consider the approaches to optimal control distributed system with random variations of structure.

Problem statement

The block diagram of typical stochastic distributed information system is shown on fig. 1.

The total (end-to-end) control delivery of data from one terminal node to another one is very interesting and the most promising approach to optimisation of information and communication systems.

It's necessary to synthesise corresponding methods and practical algorithms of such control.

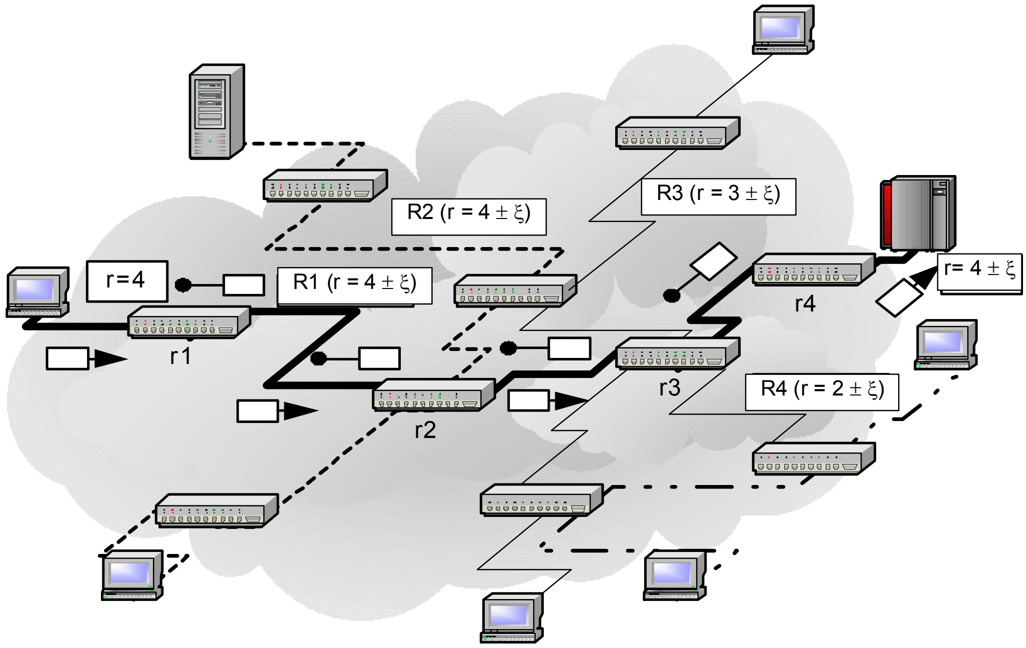

Fig. 1. System with a random delivery delay
ξ is normally distributed delay with average m_ξ and variation σ_ξ:
$\xi \sim N(m_\xi, \sigma_\xi)$; in general case $\xi \in \Xi = \{\xi_1, \xi_2, \ldots, \xi_n\}$; m_ξ, are considered priori known

From beginning let's consider the system with a deterministic delivery delay as approach to desired distributed information system with random delivery delay.

Let a data packet containing D bytes of useful information and H header bytes be transmitted to the transport system for delivery of bytes to the receiver of information.

Then the delivery time of the data packet from source A to receiver B via r switches, each of which introduces a packet delay per byte clock cycle, will be equal to

$$T_{A\to B}^{D} = D(r+1) + \sum_{i=1}^{r+1} h_i$$

normalised intervals. If data packet delivers to r^{th} router in

$$T_{A\to r}^{D} = D + h_1 + D + h_2 + \ldots + D + h_r = rD + \sum_{i=1}^{r} h_i$$

normalised intervals, where $h_1 = h_A$.

Since the packet delivers from r^{th} router to terminal node (host receiver) in $T_{r\to B}^{D} = D + h_B$ normalised intervals, then total time of delivery is equal

$$T_{A\to B}^{D} = T_{A\to r}^{D} + T_{r\to B}^{D} = rD + \sum_{i=1}^{r} h_i + D + h_B =$$

$$= D(r+1) + \sum_{i=1}^{r+1} h_i,$$

where $h_{r+1} = h_B$.

If the message consists of n packets, total delivery delay is equal

$$T_n^D = \frac{D}{n}(r+1) + \sum_{i=1}^{r+1} h_i + (n-1)\left(\frac{D}{n} + \max\{h_i\}\right) =$$

$$= \frac{D}{n}(r+n) + \sum_{i=1}^{r+1} h_i + (n-1)\left(\max\{h_i\}\right).$$

If we use criterion function

$$\Psi\{N\} = \left(T_N^D\right)^2, \qquad (1)$$

and optimisation of functional (1) actually is terminal problem, then the approach to optimal control is rather simple:

$$\Psi\{N\} = \min_u \left(T_N^D\right)^2 = \\ = \left[aT^D(N) + bu(N)\right]^2 \to u(N) = \\ = -a\left[T^D(N)\right]/b,$$

where feedback coefficient is *a*, and system gain is *b*. In other words, the more delivery delays, the more system gain.

Unfortunately, system with random delay of delivery doesn't allow getting so simple control law. Let's consider the complicated approach for this system model.

System with random delays. Dissolving the problem of end-to-end network control

If we have delivery system with random delays, its equation has random feedback coefficient $\tilde{a}$: $\tilde{a} \sim \mathbb{N}\left\{m_\xi, \sigma_\xi^2\right\}$ is normally distributed random value with average m_ξ and variation σ_ξ^2, which we consider as prior known. Then $T_n^D \to \mathrm{M}\{\xi_n\} = \hat{\xi}_n$, where M is symbol of mathematic expectation (average). Suppose the stationarity of process of delay variations ($m_\xi = \text{const}, \ \sigma_\xi^2 = \text{const}$) on the observation interval, we get the criterion function in such mode:

$$\Psi\{N\} = \min_u \left(\hat{\xi}_N\right)^2 = \\ = \left[a\hat{\xi}(N) + bu(N)\right]^2 \to u(N) = \qquad (2) \\ = -a\left[\hat{\xi}(N)\right]/b,$$

where $b = \Xi\left[\tilde{a}\left(m_\xi, \sigma_\xi^2\right)\right] = c \cdot \tilde{a}\left(m_\xi, \sigma_\xi^2\right)$, *c* — constant, which is determined during control procedure.

Now let's consider the most common case — system with a random delivery delay and with additional noise η_n in observations.

Correspondingly, criterion function $\Psi(N)$ as dissolving of terminal problem (3) is

$$\Psi\{N\} = \min_u \left(\hat{\xi}_N + \eta_n\right)^2 = \\ = \left\{a\left[\hat{\xi}(N) + \eta_n\right] + bu(N)\right\}^2 \to u(N) = \qquad (3) \\ = -a\left[\hat{\xi}(N) + \eta_n\right]/b,$$

and total time of delivery is, as it were, “twice” — random value:

$$T_n^D \to \mathrm{M}\{\xi_n\} = \hat{\xi}_n + \mathrm{M}\left[\eta_{ns}\right] + \mathrm{M}\left[\eta_{no}\right] = \mu_n, \\ \eta_n = \mathbb{N}\left(m_\eta, \sigma_\eta^2\right).$$

In this case total time of delivery T_n^D

$$T_n^D \to \mathrm{M}\{\xi_n\} = \hat{\xi}_n + \mathrm{M}\left[\eta_{ns}\right] + \mathrm{M}\left[\eta_{no}\right] = \mu_n,$$

where ξ_n — average of random delivery delay, caused by randomness of data processing; η_{ns} — observation noise; η_{no} — noise in system, ξ_n, η_{ns}, η_{no} are mutually independent random values.

Let's write the equation of control system. We consider specified system state: $T^D(0) = T_0^D$. Then

$$T_n^D \to \mathrm{M}\{\xi_n\} = \hat{\xi}_n + \mathrm{M}\left[\eta_{ns}\right] + \mathrm{M}\left[\eta_{no}\right] = \mu_n.$$

Comparing the formulas (2) and (3) we can make a conclusion then control, which is optimal (on observation interval) for system with random delays is not optimal for “twice” — stochastic system. At least it may be asymptotically optimal in current point.

So all best we do is synthesis of linearised optimal control in the mode $u_{N-1}^* = \psi\left(\mu_{N-1}, u^{N-2}\right)$, which recurrently minimises the functional of delivery delay in complex stochastic system.

So the total (end-to-end) control delivery of data in strict statement is possible only for full prior information about parameters and state of the information and calculating network. However, we can consider the recurrent linearised optimal control as asymptotically optimal end-to-end one. The most promising in this case is the stochastic optimisation of systems with random parameters (Robbins-Monroe and Kiefer-Wolfowitz procedures). Robbins-Monroe procedure is more preferable for a comprehensive analysis. Since a priori information is not enough, from Bayesian optimisation, we move on to optimisation with a minimax criterion with the least favourable distribution (LFD). We select the LFD in according to the information-entropy criterion.

We may note that using cross-layer design in network system with controlled configuration (as in SDN [4]) will give some enhancing data delivery, but this conclusion needs additional learning.

Conclusion

We have researched the information and calculating network as complex system with different modes of stochasticities. The recurrent linearised optimal control can be considered as asymptotic case of end-to-end control.

The degree of compliance proposed mode of control to strict end-to-end one depends from the stationarity of observed processes, rate of control system reaction on variations and disturbances etc. These problems represent significant interest and their dissolving will give good perspectives for minimization of data delivery delay in modern distributed systems with distant spaced elements.

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END-TO-END CONTROL AND OPTIMISATION IN INFORMATION AND CALCULATING NETWORKS

Distributed systems and networks of computers assume the presence of multiple nodes interacting with each other through a packet switching network. Each node generates data packets, consisting of a certain number of bytes of useful information and bytes of service information, such as: node addresses, data type, checksum, etc. A packet switching network consists of a set of switching equipment; during each data transfer between nodes, a path is chosen that includes a certain amount of this equipment. The article describes a distributed information and computing system, controlled by all nodes from a single control center. A method for optimal control of such a system by the criterion of minimum data delivery time has been developed. Given that the delivery time of packets depends on the number of switching equipment that they pass, various types of network interference, internal and external noise in the monitoring channels and inside the control object are analyzed. It is shown that in the presence of random delays in the delivery of data and noise in the observations, end-to-end system management should be considered as an asymptotic approximation. It is proposed to solve this problem by means of linearised recurrent control minimizing the functional of delaying the delivery of packets in a system with arising stochasticities. This approach opens up good prospects for minimizing data delivery delays in modern distributed systems with remote spaced elements. And taking into account the unified control center, it makes it possible to create an intelligent subsystem for analyzing requirements in the data packet transfer system to eliminate downtime in the data delivery environment.

Keywords: distributed information and computing system; controlled system; data delivery delay; linearised recurrent control.

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НАСКРІЗНЕ УПРАВЛІННЯ ТА ОПТИМІЗАЦІЯ В ІНФОРМАЦІЙНО-ОБЧИСЛЮВАЛЬНИХ МЕРЕЖАХ

Розподілені системи і мережі комп'ютерів припускають наявність безлічі вузлів які взаємодіють між собою через мережу комутації пакетів. У кожному вузлі генеруються пакети даних, що складаються з певної кількості байт корисної інформації і байт службової інформації, таких як: адреси вузлів, тип даних, контрольна сума, тощо. Так як мережа комутації пакетів складається з безлічі комутаційного обладнання, то при кожному сеансі передачі даних між вузлами вибирається шлях, який включає в себе певну кількість цього обладнання. У статті розглянута розподілена інформаційно-обчислювальна система, керована усіма вузлами з єдиного центру управління. Розроблено метод оптимального управління такою системою за критерієм мінімального часу доставки даних. З огляду на те, що час доставки пакетів залежить від кількості комутаційного обладнання, яке вони проходять, проаналізовані різні види перешкод мережі, внутрішніх і зовнішніх шумів в каналах спостереження і всередині об'єкта управління. Показано, що при наявності випадкових затримок доставки даних і шумів в спостереженнях наскрізне управління системою слід розглядати як асимптотичне наближення. Запропоновано розв'язувати цю задачу шляхом лінеаризованого рекурентного управління, що мінімізує функціонал затримки доставки пакетів в системі з виникаючими стохастичностями. Даний підхід відкриває хороші перспективи для мінімізації затримок доставки даних в сучасних розподілених системах з віддаленими рознесеними елементами. А з урахуванням єдиного центру управління дає можливість створення інтелектуальної підсистеми аналізу вимог в системі передачі пакетів даних для усунення простоїв в середовищі доставки даних.

Ключові слова: розподілена інформаційно-обчислювальна система; керована система; затримка доставки даних; лінеаризоване рекурентне управління.

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СКВОЗНОЕ УПРАВЛЕНИЕ И ОПТИМИЗАЦИЯ В ИНФОРМАЦИОННО-ВЫЧИСЛИТЕЛЬНЫХ СЕТЯХ

Распределенные системы и сети компьютеров предполагают наличие множества узлов взаимодействующих между собой через сеть коммутации пакетов. В каждом узле генерируются пакеты данных, состоящие из определенного количества байт полезной информации и байт служебной информации, таких как: адреса узлов, тип данных, контрольная сумма и т.п. Сеть коммутации пакетов состоит из множества коммутационного оборудования, при каждом сеансе передачи данных между узлами выбирается путь, который включает в себя определенное количество этого оборудования. В статье рассмотрена распределенная информационно-вычислительная система, управляемая всеми узлами из единого центра управления. Разработан метод оптимального управления такой системой по критерию минимального времени доставки данных. Учитывая, что время доставки пакетов зависит от количества коммутационного оборудования, которое они проходят, проанализированы различные виды помех сети, внутренних и внешних шумов в каналах наблюдения и внутри объекта управления. Показано, что при наличии случайных задержек доставки данных и шумов в наблюдениях сквозное управление системой следует рассматривать как асимптотическое приближение. Предложено решать эту задачу путем линеаризованного рекуррентного управления, минимизирующего функционал задержки доставки пакетов в системе с возникающими стохастичностями. Данный подход открывает хорошие перспективы для минимизации задержек доставки данных в современных распределенных системах с удаленными разнесенными элементами. А с учетом единого центра управления дает возможность создания интеллектуальной подсистемы анализа требований в системе передачи пакетов данных для устранения простоев в среде доставки данных.

Ключевые слова: распределенная информационно-вычислительная система; управляемая система; задержка доставки данных; линеаризованное рекуррентное управление.

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