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Formalization of load management mechanisms in sensory networks

In existing methods of load management in networks, in most cases, decision-making is based on one indicator. But this approach add to the standard network problems that are characteristic of the wired and optical lines problems with the presence of interference in communication lines, the fading of signals,. the structure of the signal and others. These issues require the development of a mathematical model of multicriteria optimization of the quality of service and functioning of sensor networks using the principle of equity based on the stability of the proposed models.

Until recently, the only mechanism for controlling loads and queues in telecommunication networks was the best-effort mechanism, which is based on rejecting packets when buffer overflows [1]. In this queuing mechanism, feedback was not provided for the transfer node, restriction of the input load, or the classification of data flows by certain parameters (priority, lifetime of the package, type of data, etc.), which leads to unfair processing of individual flows, violation of synchronization streams, increasing the likelihood of loss of packets with high priority.

At the level of information flow management in the router, the use of conventional methods of dropping packets is not constructive. To eliminate the disadvantages listed, the following methods of load management were proposed [2, 3]:

- methods for managing traffic at the entrance to the network, which include traffic conditioning, traffic shaping and traffic policing, such as the Leaky Bucket and the "ticker basket" (Token Bucket);

- methods for managing the load inside the network (ie, managing the bandwidth of the network and distributing network resources), which include the "window mechanism", as well as different ways of forming queues, such as a weighted fair line - WFQ (Weighted Fair Queue), weighted honest queue on basis bandwidth - CBWFQ / CBQ (Class Based WFQ);

- preventive methods to prevent overload before it occurs and methods of eliminating overload that has already occurred. These methods include: Selective Packet Discard, Selective Packet Discard algorithm, Explicit Congestion Notification ECN algorithm, Random Early Detection RED, and others.

The last category of management mechanisms refers to the active mechanisms for organizing packet queues - AQM-mechanisms (Active Queuing Management). These methods are the most versatile and effective for use in BSM. We will develop a model of the functioning of the BCM taking into account the feedback.

Control overload on the basis of the interaction of TCP / AQM-mechanisms combines two mechanisms:

1) TCP overload management, implemented by changing the window size of the transmission (cwnd), due to the adaptation of the rate of transfer of data packets

between the end nodes to the communication channels, based on information about the extent of its overflow (overload);

2) overload management in intermediate routers AQM, which is implemented through algorithms for handling queues at ports. These mechanisms form a channel overload function, which, in turn, is a measure for the task of cwnd and the intensity of the packet data transmission by the source. Thus, a feedback control system is formed, though traditional TCP algorithms do not directly use AQM information.

Approaches to determining the extent of overload in different versions of TCP differ from each other. Thus, as a safety overload in TCP-Reno, the probability of packet loss is used, and in TCP-Vegas, the delay in queues. Routing methods can include RED (Random Early Detect), REM (Random Exponential Marking), AVQ (Adaptive Virtual Queue), SAM (Self-normalized Additive Marking), and others.

In works [4,5] it is proposed at the stream level to enter the feedback between the network channels and data sources. Moreover, building a network protocol for BSM is based on the same principles that guide the leading TCP networks, but requires some changes in control algorithms. Simplified structural dynamic scheme of a functioning feedback system is presented in Fig. 1. The scheme works in the following way. Sender nodes send packets to the network. The total packet stream passing through a given data channel has packet speeds per unit time. With a high intensity of the input stream that exceeds the limitations of the router, all non-serviced packets are transferred to the buffer to avoid rejection. This situation on the router is regarded as the initial stage of network overload. To prevent a global overload, an overload signal is transmitted through the feedback channel to the sources.

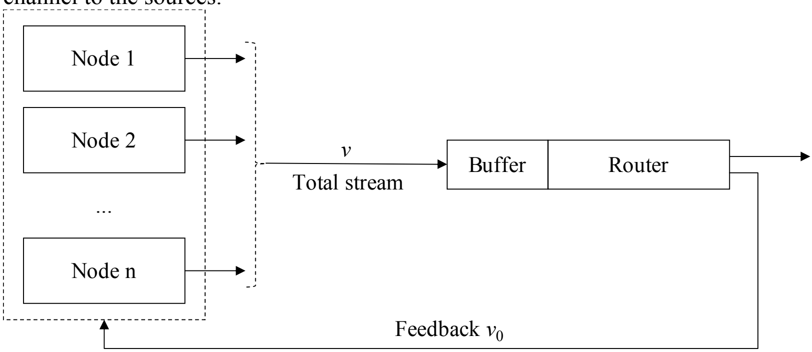

Fig. 2.1 Structural dynamic scheme of a functioning system with feedback

Let $c(v)$ be the corresponding price of a unit of stream (delay in queues, probability of marking packets by routers, etc.). The price of data transmission on this channel is proportional to the stream rate (λ) and equal $k\lambda c(v)$ (k-constant). According to the model [1], the processing speed of packets varies according to the additive increase and multiplicative reduction (AIMD) algorithm (Additive Increase and Multiplicative Decrease). Following this scheme of speed adjustment, in the end nodes redundancy and "pay" (load) for using the channel in the network to the equilibrium state with their variants of "payment" (load) is carried out. In the case when the system cope with the load, after the transition regime, it seeks to balance, in which "supply and demand" are balanced.

The task of multicriteria optimization to provide the required level of service quality

Let x be a solution determined by the admissible set of solutions X, formed by a set of controlled parameters. The quality of the solution is evaluated by many criteria: $K = \{k_1, k_2, ..., k_n\}$, where $k_1, k_2, ..., k_n$ – set of service quality criteria in BSM. It is known to map the set of solutions to the set of criteria $x \rightarrow K$ and the relative importance of each of the criteria $\Lambda = \{\lambda_1, \lambda_2, ..., \lambda_n\}$. We need to find the best solution

$$x^0 = optG\left[K(x), \Lambda\right], \; x \in X \tag{1}$$

The solution to this problem does not cause complications in the event that the known operator Λ is defined and the type of the optG operator is defined, that is, a given generalized criterion or rule that allows us to arrange the possible solutions [2].

One of the most common approaches to problem solving (1) is based on the construction of a multicriterial problem to one-quaterial one. This approach is based on the theory of utility, according to which it is assumed that there is some generalized assessment of the value or usefulness of any solution. In this case, the formation of a compromise scheme is associated with a kind of utility function

$$P = F\left\{K_1(x), K_2(x), ..., K_n(x),\right\} \tag{2}$$

To solve this problem it is necessary to justify the kind of utility function of local criteria $\xi(K_i)$.

The function of the utility of local criteria should be universal and well adapted to account for the specific features of specific systems, their goals and criteria. To do this, it must meet the following requirements: be dimensionless; have a single measurement interval; be invariant to the local extremity type.

The specified function corresponds to the function of the type:

$$\xi_i(K_i) = \left(\frac{K_i - K_{i_{нх}}}{K_{i_{нл}} - K_{i_{нх}}}\right)^{\alpha_i} \tag{3}$$

where K_i is the value of the i-th criterion for the system variant;

$K_{i_{нл}}$, $K_{i_{нх}}$ – its best and worst value, corresponding either to the limits of the area of the permissible change of the corresponding parameters of the system, or programs of the approximate area of compromise; α_i - nonlinearity indicator.

The utility function (3) characterizes the degree of proximity to the local optimum by the K_i criterion. To determine the limits of approximation of the compromise area of X^P use the following method: on the set of allowable solutions X perform optimization for each of the criteria, as a result determined by the extreme criterion of the decision

$$X_i^0 = \arg \underset{x \in X}{extr} K_i(x), \; i = \overline{1, n} \tag{4}$$

and the corresponding values of all the criteria for $j = 1, \ldots, n$. Then we can imagine how

$$K_{i_{нх}} = \begin{cases} \max\limits_{j} K_i\left(x_j^0\right), K_i(x) \to \min; \\ \min\limits_{j} K_i\left(x_j^0\right), K_i(x) \to \max. \end{cases} \qquad (5)$$

The X^P area includes a compromise area (the Pareto region), since for it the necessary condition for compromise is true - inclusion of global extremes of all criteria. The X^P region is wider than the Pareto region, since it includes some subsets of the area of agreement, so in the general case, compromise solutions selected from the XP area must be checked for membership of the Pareto area.

The considered utility function (3) is not the only one possible [1]. The choice of its specific type and quantitative parameters is a heuristic operation.

To select a single solution in the field of compromise, justify the axiomatics and, on the basis of it, form a rule (compromise scheme) for making a decision. To solve this problem, additional information is needed which can be obtained by analyzing and formalizing the features of the system's purpose.

A generalized criterion for certain quantitative values of the weight coefficients w_i of the individual criteria of $K_i(x)$ or of their utility functions $\xi_i(K_i)$ takes the following form:

$$J(k) = \max_{x \in X} \sum_{i=1}^{n} w_i \xi_i\left[K_i(x)\right],\ i = \overline{1,n},\ \sum_i w_i = 1.$$

Under the solution of the multicriterial problem, we will understand the set of controlled variables that provide the optimum simultaneously to all the criteria of optimality introduced. Define a set of controlled parameters and a set of optimality criteria. In accordance with the SLA [6] agreement, we define three basic parameters of the quality of services for wireless sensor networks (WSN) that must be agreed upon by network devices when establishing a connection when implementing the principle of self-organization: the authenticity of the information being transmitted, the delay in the transmission of packets, the percentage of lost packets.

Conclusions

Taking into account the construction of mathematical models of WSN, the following conclusions can be drawing:

1. The sensor system and its elements are dynamic objects that change in time, the state of which depends on both internal factors (turning on / off individual elements, changing modes of operation, etc.), and from external (state of the object of monitoring , level of interference in communication channels, change of traffic). An adequate mathematical model of such a system, which describes its dynamic state, is the system of ordinary differential equations. This system can be both random and regular, which is allowed in some cases, especially in simple situations.

2. The developed mathematical model of the dynamics of the functioning of the WSN in the general case is a system of difference equations, where as the state the rate of data transmission and the source in the corresponding channel is selected, taking into account the presence of correction moments, packet loss and random

effects acting on these channels. The model represents the dynamics of TCP with heterogeneous RTT round-trip time.

3. For the analysis of the features of the operation of the WSN, a mathematical model of information flows with different distribution functions operating at the input of the node of the BSM distribution was proposed.

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