BAND WIDTH MAXIMIN FAIR OPTIMIZATION IN MESH NETWORKS BASED ON PERCEIVED QUALITY OF SERVICE

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Abstract: The paper presents an analysis of perceived quality of service (PQoS) as an objective function for network management. It provides a formulation of the problem a method for preserving PQoS wireless mesh network subscribers and suggests an algorithmic solution of the formulated problem in wireless mesh networks with centralized control.

Keywords: Wireless mesh network, network resource management, perceived quality of service, PQoS, maximin optimization, fair level of PQoS.

Introduction

Mesh-networks are the new promising concepts for broadband wireless networks which have a feature of self-organized network architecture and follow capabilities:[1]

- Wireless transport link network application, networking typology "all-to-all";
- Network scaling (footprint variation and dataware density) in self-organizing mode;
- Network fault-tolerance;
- Low cost of network scan.

Realistic examples of embedded mesh-technologies in wireless networking involve the implementation of the following standards:

1. Wireless Metropolitan Area Networks (WMAN) – IEEE 802.16j;
2. Wireless Local Area Network (WLAN) – IEEE 802.11s;
3. Wireless Personal Area Networks (WPAN) – IEEE 802.15.4.

One of the main critical factors of mesh networks development influencing on preset level of quality service (QoS, Quality of Service) is complexity providing for all net-

INFORMATION & SECURITY. An International Journal, Vol.28, No. 1, 2012, 133-145.

work subscribers.[2] ITU-T recommendation E.800 basically defines QoS as "the collective effect of service performance which determine the degree of satisfaction of a user of the service."

Means of QoS for traditional wire line networks (WLN) cannot be used directly in wireless mesh networks (WMN) due to the following limitations:[3]

- Radio links have bandwidth bottleneck, high interference between paths, data deference and data variation deference comparing to modern wireline;
- Radio link instability as the result of interference and also subscriber mobility;
- WMN output degradation in case of WMN zoom;
- The complexity of wireless access technologies which demands different QoS mechanism embedding into various network segments and complicate the interoperability between these mechanisms.

Choice argumentation of perceived quality of service (PQoS) as an integral quality service index

Over the time of ten years the conceptual model of cross-layer architecture of wireless network management system has been designed.[4] Cross-layer architecture of wireless network management system provides coordination and integration levels of standard open systems interconnection (OSI) according to objectives and functions of management and intellectualisation of decision-making procedure. Main difficulties on creation of cross-layer architecture of wireless network management is determination of necessary parameters using between the level of OSI and management function and this makes it possible to get user and (or) network, zone optimization.[5]

One of applied problems of network management connected with providing QoS, is the problem of network utility maximization. For the first time the problem of network utility maximization was formulated by Kelly.[6] A number of methods have been suggested for maximizing mesh network utility.[7] The problem of mesh network utility maximization which consists of E – resource elements, F – created information flows, is composed of searching such vectors of resource allocation of mesh-network which satisfies the condition (1):

$$\mathbf{x}^* = \arg \max_{\{x_f\}\in\Omega} \left(\sum_{f\in F} U_f\left(x_f\right) \right) \tag{1}$$

subject to

$$\mathbf{R} \times \mathbf{x} \le \mathbf{C}, \ \mathbf{x} \ge 0,$$

where x_f – network resources allocated for information flow f; $U_f(\{x_f\})$ – utility function value for information flow f on allocation of x_f network resources; Ω - number of probable variants of resource allocation between information flows in network; $\mathbf{R} = (R_{ef})_{|E|\times|F|}$ - resource allocation matrix of network elements between information flows; $\mathbf{x} = (x_f, f \in F)$- vector of resource allocated to information flows; $\mathbf{C} = (C_e, e \in E)$ – vector of resource element capaciousness.

Complex interconnection between network parameters and ambiguity of influence on QoS determines originality of parametrization of objective optimization function as the several variable function. Thus in the model of mesh network utility maximization,[8] the objective function is specified as the function depending on one variable – bandwidth.

Perceived quality of service (PQoS) can be used as the integral performance index which includes network effects as well as application software effect.[9] PQoS - is the assessment of information service quality from the point of perceiving by a user as by a subscriber of given service. Recommendation ITU-T P.830 sets five-score scale MOS (Mean Opinion Score) for the PQoS estimation. During recent years the methods of objective assessment for PQoS have been developed and were examined by international verification for:

- services of voice transmission, recommendations ITU-T G.107, P.563, P.862;
- services of video translation, recommendation ITU-T J.247;
- services of audio broadcasting , recommendation ITU-T BS.1387;
- services of data transmission, recommendation ITU-T G.1030, G.1040.

Objective assessment of PQoS can be automated. Values of multidimensional array of PQoS - $\{q_i\}$ can be determined for every information service functioning in network. Values of PQoS - $\{q_i\}$ depend on dedicated resource, network parameters, functionality of application software (subscriber equipment) which realizes given service

$$\{q_i\} = F(\{R_i\}, \{p\}, \{E_i\}),$$

where q_i - value of PQoS according to the scale MOS for information service i, $i \in 1,..,m$; m – the number of information services functioning in network; $\{R_i\}$ – range of service resources dedicated for information service i; $\{p\}$ - set of indices specifying network; $\{E_i\}$ – set of factors affecting on PQoS features of realizing application software and (or) subscriber equipment.

Figure 1 shows the dependence of PQoS on:

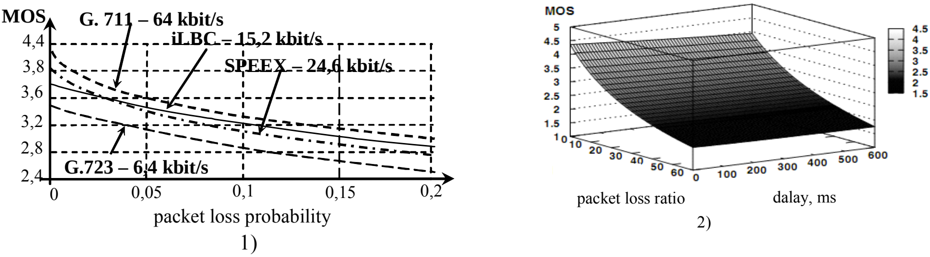

Figure 1: PQoS as a function of (1) packet loss probabilities for different voice codecs [10] and (2) loss rate and delay for SPEEX codec (24,6 kbit/s).[11]

- network resources – bandwidth;
- network indices – packet loss probability, delay in packet delivery;
- features of realizing application software – a type and a speed of information flows, using codec.

Our earlier work treated the efficiency of PQoS as an index at task of mesh-network utility maximization.[12] Subject to convex objective function, problem solution (1) satisfies problem specification of proportionally fair and maximin fair network allocation of resources between information flows. Proportional and maximin fairness does not guarantee the accomplishment of specified preset level of PQoS for some information flows in network. The method of providing maximin fair level of PQoS in mesh network at the guaranteeing preset levels of PQoS for maximum possible quantity of subscribers is considered in this paper.

Defining problem of cross-level optimization for providing maximin fair level PQoS of wireless mesh network subscribers

The mesh network architecture based on retransmission is used in WMN of WMAN scale. Figure 2 given architecture is standartized for WiMax technology of mesh networking via IEEE 802.16j, and for LTE technology given architecture is considered as promising variant.[13] Network components are: base station (BS), relay station (retransmitting station, RS), subscriber station (SS). RS can operate in two modes: transparent and non transparent. In the first mode RS compiles only data and do not compile preamble and control fields. SS is managed directly by BS, herewith SS do not interact logically with RS (knowing nothing about RS existing). In the second mode RS transmit data and also preamble and all executive communications. The SS is connected logically and physically with RS. RS can be fixed, nomadic (transportable RS), mobile types. Reliable and high-duty technologies which are able to guarantee required QoS level provide the communication between BS. The radio recourse limitation, radio link and mobile subscribers instability in BS and RS coverage area are the major cause of QoS fade-down. The BS and RS radio interface bandwidth is the general resource of wireless mesh network.[14]

The proposed solution of optimization problem concentrates on maximin fair level QoS providing in wireless mesh network due to bandwidth adaptive distribution, multimedia data variable-rate coding with a glance of packet loss probability between network devices. Increase of mesh-network radio resource application effectiveness is provided by problem solution.

Initial assumptions. Optimization problem solution based on the follow assumptions:

- RS operate in nontransparent mode and network elements are connected with the similar radio interface (carrier frequency), control mode in mesh networks is centralized;
- mechanisms of routing classification , information flows isolated processing, packet scheduling, traffic shaping are realized in WMN;
- deterministic access to a radio channel with feature of determination to all information flows of bandwidth reservation with discrecity Δr;
- BS and SS service feedback with feature of data accessing about packet loss probability from a receiver;

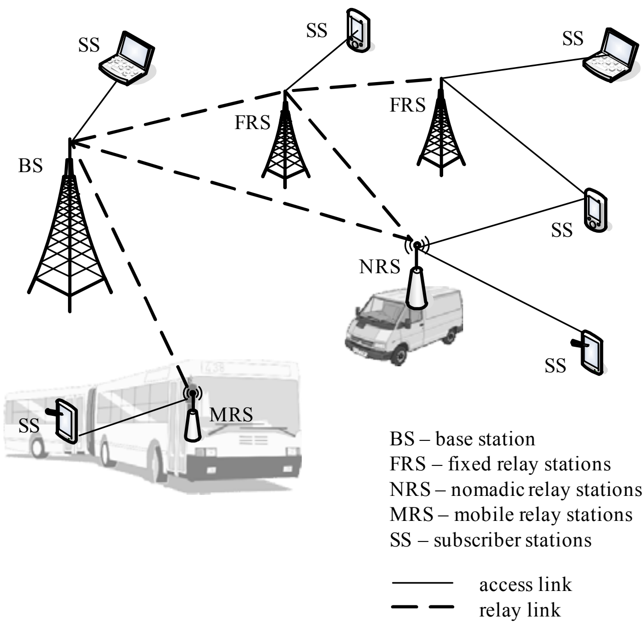

Figure 2: The structure of an IEEE 802.16j WMN.

- multimedia transcoding feature as the method of change in realtime rate coding and (or) data representation format of SS and BS.

Estimation analysis shows that all mechanisms are realized in up-to-date technologies, except the transcoding mechanism.[15] Modern data encoding methods allows to put into practice real time transcoding at BS as well as subscriber equipment.

Initial data. Follow initial data are used to solve the optimization problem:

- m –the number of RS in mesh-network;
- R - bandwidth value of BS, RS, SS interfaces (bit/s);
- Δr – bandwidth incremental, which can given BS or RS for information flow (bit/s);
- k – the number of information flows competing for access;
- Information coding methods in network information flows;
- Information flow routs;
- p_i - average probability of packet loss for each information flow, $i \in 1,...,k$;
- PQoS value array for each information flow in MOS scale, object to flow rate, packet loss probability and coding method.

$$\{q_i(r_i, p_i, E_i)\} = \{q_1 (\Delta r , p_i, E_i), q_2 (2\Delta r, p_i, E_i), \dots , q_i(B_i\Delta r, P_i, E_i)\},$$

where $B_i = \lfloor R_i^{max}/\Delta r \rfloor$; R_i^{max} - maximum bandwidth for information flow i (bit/s).

PQoS defined level of guarantee providing for network information flows maximum quantity can be possible only if maximin principle is integrated into PQoS problem definition. In contrast to classical computer network maxmin principle, this method proposes to define for each network traffic classes the follow levels:

1. PQoS minimum level provides required minimum for data exchange quality;
2. PQoS comfort level provides comfort quality for data exchange;
3. PQoS maximum level provides maximum quality of data exchange for the given traffic class (information service).

The problem is to find such a bandwidth distribution vector between mesh-network information flows under the following problem situations:

$$\{r_i\}^* = \arg\max_{\{r_i\}\in\Omega}\left(\sum_{i=1}^{k} q_i\left(r_i, p_{i,}, E_i\right)\right) \quad (2)$$

$$n^{min} \to \max, \quad (3)$$

$$n^{com} \to \max, \quad (4)$$

subject to

$$\sum_{i=1}^{k} r_i \le R \quad r^* = (r_i, i = 1,..,k)$$

where $r^* = (r_i, i = 1,..,k)$ - bandwidth distribution vector between information flows providing problem solution (2); Ω - multivalued bandwidth allocation vector between k-information flows, with the discrecity of bandwidth variation (Δr); n_{min} – the number of information flows for PQoS minimum level; n_{com} – information flows quantity for PQoS comfort level; $\Delta \mathbf{R} = \left(\Delta R_{ji}\right)_{|m+1|\times|k|}$ - bandwidth allocation array of BS and RS radio interface in mesh-network between information flows; $\tilde{\mathbf{N}} = (R_j, j = 1,..., m+1)$ - BS and RS radio interface bandwidth vector.

Using greedy algorithm we can achieve problem (2) solution. The choice of given method can be specified by:

1. Bandwidth array responds to standard set of the transmission rate. Thereby the method is discrete and so solution components have to compose discrete;
2. Computation complexity of greedy algorithm in comparison with dynamic programming or analytical solution search is much less.

Greedy algorithm availability in optimization problem (2) solution subjects to:

1. Object function additive mode;
2. Solution about bandwidth part determination depends only on free bandwidth value. Determination accepts in each iteration;
3. Guarantee of achievement under application of “greedy” algorithm of Pareto optimality, also object function description and primary limitations corresponding to optimization problem.

Algorithm for solving problem (2) was suggested by one of the authors.[16] The original algorithm was used for maximin bandwidth allocation in BS service area.

Cross-level algorithm of providing maximin fair level of PQoS WMN subscribers

Algorithm of cross-level optimization for providing maximin fair level of PQoS in mesh network is initialized by BS if it is necessary to reallocate mesh-network resources in the beginning (end) of communication session or with fixed frequency. According to stochastic stability of control algorithm resources allocation of network [17] must satisfy to relation:

$$T_r \approx T_c < T_s ,$$

where T_r – average time that necessary for realizing resources allocation; T_c – correlation window of network parameter changes; T_s – mean connect time.

Algorithm solution of assigned problem consists of three main stages. At the first stage due to resource allocation of the base station (BS) and the relay station (RS) between subscriber information flows, minimum level of PQoS for maximum numbers of information flows is provided in mesh network (condition (3)).

Since utilize resource is bandwidth radio interfaces BS и RS, resource costs are calculated by the mean of the following formula:

- for route which pass only through RS $C = 2ny\Delta r$;
- or route which pass only through RS BS $C = 2ny\Delta r + y\Delta r$,

where n – the number of RS, where the route of information flow in mesh-network passes; y - the capacity of resource elements for information flow $y = \lfloor r_i/\Delta r \rfloor$.

If the BS bandwidth is not enough for providing minimum level of PQoS for all information flows, denial of service for flows with minimum value of ratio ($PQoS_{min}/C$) occurs.

At the second stage, in the presence of bandwidth reserve after providing minimum level PQoS for information flows, the bandwidth is given for maximum possible number for information flows, what provides the achievement of comfort level PQoS (condition (4)). Priority is for only those information flows that have maximum value of ratio ($PQoS_{comf}/C$).

At the third stage, in the presence of bandwidth reserve after providing comfort level PQoS for information flows, the bandwidth reserve is allocated between information flows for the purpose of maximization complete value of PQoS (2) in the network segment with the usage of an original algorithm proposed by one of the authors.[18] In each cycle of the third stage of algorithm the bandwidth is given information flow with maximum value of ratio "increment of PQoS / growth of resource costs," detailed description of this algorithm component is given in an earlier paper.[19]

Algorithm performing stops if each information flow gets maximum required bandwidth R_i^{max} (if mesh-networks function in the underload mode), or in case of resources exhaustion of radio interface, where information flows pass, subject to $r_i < R_i^{\max}$.

The results of algorithm performing are a bandwidth allocation vector between information flows and bandwidth allocation matrix of radio interfaces BS и RS in mesh-network between information flows. This vector provides the problem solution (2). The subscriber equipments (base station BS) must coordinate the speed of each information flow with the received result using transcoding for audiovisual services and limiting flow rate of data transfer.

Mathematic modelling proposed method of providing subscribers of mesh-network with maxmin fair level of PQoS

Program mathematic algorithm model of PQoS maximin fair level of wireless mesh network subscribers is designed for experimental check of the given method effectiveness. The structure of mesh network containing BS and three RS is used in this mathematic model. Wireless connection between BS and RS corresponds to Figure 3. Each RS interacts with 20 SS.

Source data under modelling:

- R - maximal value of wireless interface capacity of network equipment-1024 Kbit/s;
- Δr – bandwidth increment - 4 Kbit/s;
- k – number of information flows - 60;
- for all informational flows in network the following levels PQoS are determined:
    - minimal level of PQoS – 2,5 according to MOS scale;
    - comfort level of PQoS – 3,5 according to MOS scale;
    - maximal level of PQoS – 4,5 according to MOS scale.

Each SS form informational flow of one of two classes (a flow class is chosen stochastically at every starting algorithm):

- voice transmission with using codec SPEEX- minimun speed of a flow 4 Kbit/s, maximal speed 28 Kbit/s;
- data transmission – minimun speed of a flow 4 Kbit/s, maximal speed 28 Kbit/s.

The analysis of Figure 4 and Figure 5 shows that network resource allocation on the base of indices of PQoS predominates over network resource allocation on the base of bandwidth values.

Conclusions

Performance capability and availability of using the value of perception of quality service (PQoS) in the capacity of index of network problem management are proved in this article. The method of maximin fair level for PQoS of wireless mesh network subscribers is proposed. The given method is distinguished from known ones by

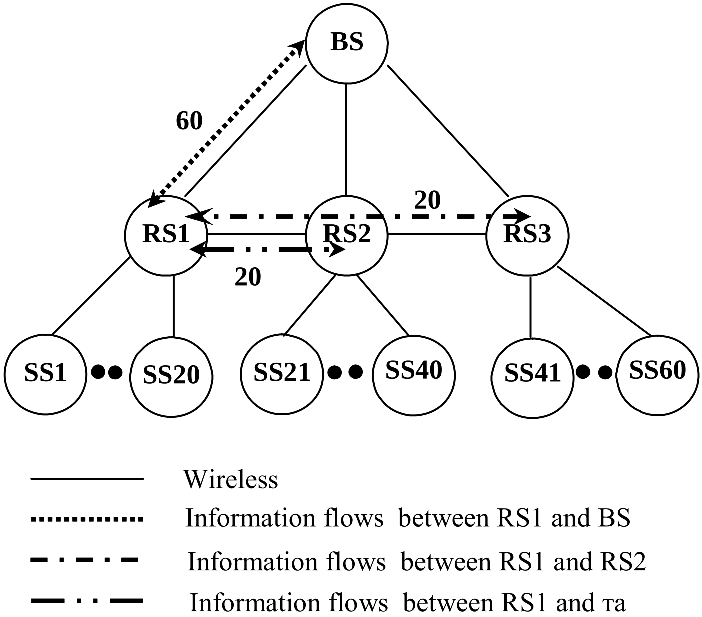

Figure 3: Network structure and directions of information flows.

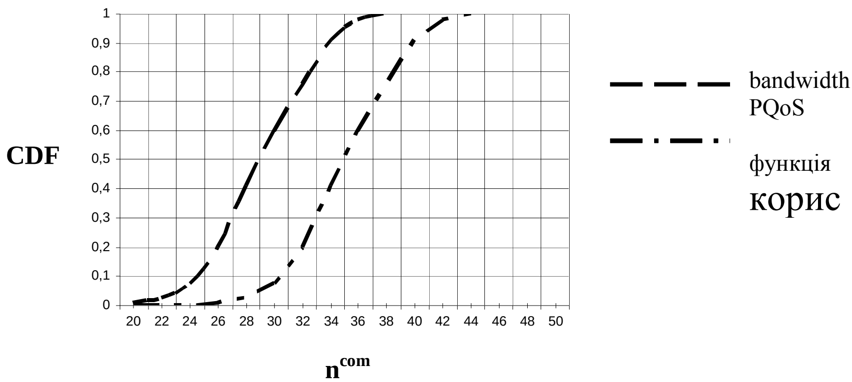

Figure 4: CDF of the number of information flows with providing a comfort level of PQoS.

using PQoS as an objective optimization function that depends on network bandwidth, noise immunity and the way to implement the information service.

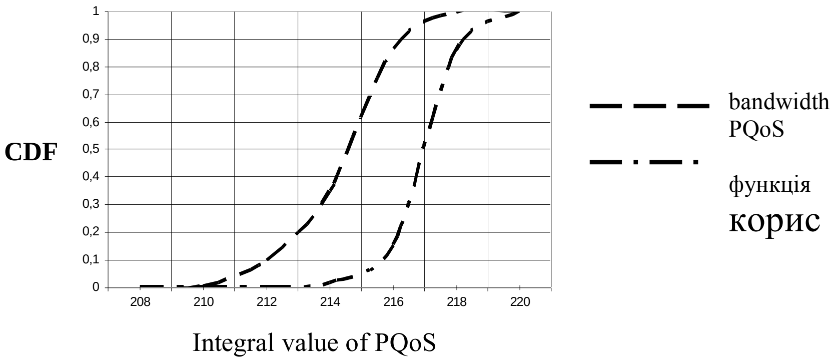

Figure 5: Integral value of PQoS undersign of different methods maximization network utility.

In further research it has been expected to expand the list of mesh network resources. The management of resources provides the problem solution of perception of maximin fair level for PQoS of wireless mesh network subscribers and also the implementation of introduced methods in wireless networks with the Ad Hoc structure.

Notes:

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