УДК 004.414.22/004.051/519.687.5

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OPTIMISATION PROBLEM STATEMENT OF DECISION-MAKING ON HANDOVER IN HETEROGENEOUS AD HOC NETWORKS

Advanced development trends of wireless networks and mobile communication are considered. It's shown that new trends of program-defined and cognitive radio require creation of metrics system for route decision-making or handover in heterogeneous wireless networks. Based on the analysis of main selected metrics we concluded that it is necessary to apply various conditions in order to make the right decision. It's shown that decision on handover in heterogeneous ad hoc networks shall be made taking into account existing various and contradictory metrics by introduction of unique metrics integrating the initial ones. It's proposed that decision-making on handover in heterogeneous wireless networks of mobile communication devices is produced on the fuzzy optimization approach.

Keywords: *wireless network, cognitive radio, metrics, Service of Quality, mobile communication device, program-defined radio system, access point.*

Introduction

Wireless ad hoc network (wireless dynamic network, wireless self-organised network) is a decentralised wireless network without constant structure. Client devices connect "on-the-fly" forming a network. Each network node attempts to transfer data intended for other nodes. Thus determination of data transfer to the node is dynamic based on network connectivity. In heterogeneous network environment parameters of different network types are in different ranges, hence relevant is the selection of the criteria for decision-making on handover, selection of optimal network route etc. Three stages of handover procedure are defined: information accumulation on accessible networks (initialization), decision-making on handover and immediate switchover. Handover method in heterogeneous wireless networks of mobile communication devices shall select the most appropriate moment of initialization and the most suitable network among all accessible.

Publications review

Handover has the following requirements: low delays, high reliability, high success level, minimum number of transmissions, support of subscriber's transparent movement, load balancing on a radio access network [1].

Metrics of resource costs. Decision-making on horizontal handover in homogeneous networks occurs on the basis of RSS metrics (Received Signal Strength) and channel availability.

In case of vertical handover in the conditions of heterogeneous networks single RSS metric is not enough, since RSS from different networks cannot be compared directly due to various characteristics of these networks. The following additional metrics received wide spread [2].

1. Number of switches (hop count) is widely used as routing metrics in existing routing protocols such as Dynamic Source Routing (DSR) [3], On-demand Distance Vector routing AODV [4] and others. Metrics does not consider distinction in transfer rates and packet loss coefficients in various network segments.

2. IEEE 802.11s Standard requires support of transfer time metrics in the channel (Airtime Link Metric) for compatibility of all devices:

$$C_a = \left(O + \frac{B_t}{r} \right) \frac{1}{1 - e_f}, \qquad (1)$$

where B_t is the number of bits in test packet;

O – overhead charges of channel access which include packets header, access protocol frames, etc.;

r - transfer rate in the channel (Mbit\s);

e_f - probability of error occurrence (the value is measured experimentally on packets by B_t length).

This metric represents transmission time estimation (in seconds) of a trial packet with B_t length taking into account possible relays due to losses in channel.

3. Expected transmissions count (ETX) is one of the first routing metrics intended for wireless cellular networks [5]:

$$ETX = \sum_{k=1}^{\infty} kp^{k-1} (1 - p) = \frac{1}{1 - p}, \qquad (2)$$

where k is the number of transmission attempts, p – probability of successful attempt.

Taking into consideration the fact that transmission shall be proved by appropriate acknowledgement ETX can be represented as follows:

$$ETX = 1/(d_f \times d_s), \quad (3)$$

where d_f, d_s are the number of expected packet transmission attempts in direct and reverse directions required for successful transmission on a concrete wireless communication channel and provision of packet reception.

ETX metric does not consider influence of various transfer rates in various wireless communication channels and various sizes of data packets. Losses increase on long paths therefore ETX metric depends on a path length.

4. Expected transmission time (ETT) defines the time required for packet transmission of S size through the channel with B transmission rate:

$$ETT = ETX \times S/B. \quad (4)$$

5. ETT and ETX metrics do not allow consideration of possibility to use various network paths. In order to search paths with lower interference level when using forwarding the paper [6] offers the metrics of the weighed cumulative expected transmission time (WCETT):

$$WCETT = (1-\beta)\sum ETT_i + \beta \times \min_{1 \le j \le k}(X_j), \quad (5)$$

where β is adjustable parameter;

X_j – the sum of expected transmission times (ETT) for all the forwards (hops) of the channel;

k – number of possible channels.

WCETT metric consists of two addends: the former defines delay from the beginning to the end of the channel whereas the latter considers a variety of channel segments throughout the path.

6. Study [7] offers metrics connecting WCETT – metrics with hop delay.

Suppose P is the path between S source node and P receiver node: $P = \{S, N_1, N_2 ... N_m, D\}$, where $\{N_1, N_2 ... N_m\}$ is a set of intermediate nodes.

Links between the nodes are the couples defined on P set:

$l_1 = \langle S, N_1 \rangle; \forall i, 2 \le i \le m, l_i = \langle N_{i-1}, N_i \rangle; l_{m+1} = \langle N_m, D \rangle$.

Thus the link metric l_i equals:

$$M_{l_i} = (1-\beta)ETT_{l_i} + \beta(DL_i - \max X_j), \quad (6)$$

where DL_i is delay of l_i link switching,

X_j is metrics maximum value of double switching on j channel.

The general path metrics is defined as the sum of link metrics: $M_p = \sum_{i=1}^{m+1} M_{l_i}$.

7. The metric considering power possibilities of network nodes for extension of HWMP routing protocol [8] predicts a maximum uptime of device in standby mode with switched off network interface which depends on remainder capacity of accumulator battery:

$$L_{max} = C/I_{min}, \quad (7)$$

where C is nominal capacity of node battery as per specification,

I_{min} is a minimum current of battery discharge.

Metric which considers power possibilities of nodes is a relative value in [0, 1] interval:

$$M_E = 1 - \frac{T_E}{T_{max}} = \frac{L_{max} + L^2}{L \cdot T_{max}}, \quad (8)$$

where $T_e = L_{max}/L + L = (L_{max} + L^2)/L$, T_{max} is a maximum T_e value included in the formula to deduce range of values ME to [0,1] segment.

Service of Quality metrics. Network mechanisms shall be used in combination with characteristics of service quality formed depending on requirements of applications. Various types of application or services require various data transmission rates, network delays, reliability and safety levels. Data-rich applications such as stream video work better if capacity is high. Applications operating real time need a minimum network delay whereas other applications are not as sensitive to network latency.

For the majority of cases the communication quality is defined by four parameters [9]:

- bandwidth refers to the width of the frequency band that a system operates in, describes nominal capacity of information transmission media;
- packet loss defines number of packets lost in network within transmission time;
- delay (latency) - amount of time it takes a bit to be transmitted from source to destination;
- jitters describe differences of delays during packet transmission.

Various types of applied tasks are critical to various metrics of communication quality. For instance, in telemedicine accuracy of delivery is more important than a total mean delay or jitter whereas in IP-telephony jitter and delay are key characteristics which are to be minimised.

In vertical handovers in the conditions of heterogeneous networks it's necessary to consider the following additional metrics for decision-making on transmission: cost of services, safety, operation conditions of mobile device, user settings.

Metrics of application level of OSI model. According to the model of providing differentiated services, i.e. DiffServ, which provides users with services with various requirements to QoS under guidelines of 3GPP consortium, defined are nine types of services which are divided into two classes depending on requirements to network resources:

- Guaranteed Bit Rate (GBR);

- Non-guaranteed Bit Rate (Non-GBR).

GBR services include real time services such as voice or video telephony, games in real-time mode with defined minimum speed rate, guaranteed rate (GBR). Non-GBR services include services without defined minimum guaranteed rate (non-GBR). Transmission bit rate can vary depending on network loading; therefore in case of overload loss of data packets occurs. In this case access control is carried out by means of introduction of aggregate maximum bit rate (Aggregate MBR, AMBR) which allows differentiation of services by priorities in maintenance. Examples of such services are e-mail, page view, and interactive games.

Rate increase or decrease within GBR minimum to MBR maximum values in GBR services does not influence mean time of data transmission; whereas variation of services provision rate without guaranteed bit rate leads to change of mean time of data transmission. Thus we can single out two types of traffic generated at services provision: stream and elastic [10].

Further we assume that the metric of service quality on applied level depends on the class of service.
Service quality on applied level for GBR services is represented as follows:

$$QoS_{MBR}\left(BR\right) = \min\left(1,\ \frac{\Delta BR_{1,n} - GBR}{MBR - GBR}\right), \quad (9)$$

where GBR is Guaranteed Bit Rate, bit per second;

MBR is Maximum Bit Rate, bit per second;

BR is an actual Bit Rate, bit per second.

Service quality on applied level for non-GBR services is represented as follows:

$$QoS_{GBR}\left(BR\right) = \frac{BR}{AMBR}, \quad (10)$$

where AMBR is Aggregate Maximum Bit Rate, bit per second;

BR is an actual Bit Rate, bit per second.

Objective of this paper is to define the optimisation task of decision-making on handover in heterogeneous wireless networks of mobile communication devices.

Method of decision-making on handover in heterogeneous ad hoc networks

Decision on handover in heterogeneous ad hoc networks shall be made taking into account existing various and contradictory metrics. One of the possible ways in this case is introduction of unique metrics integrating the initial ones. In order to simplify multi-objective task we use convolution of vector criterion into scalar applying additive convolution:

$$k(a) = \sum_{i=1}^{I} \lambda_i \frac{k_i(a)}{k_i^O}, \quad (11)$$

where λ_i is a coefficient of importance of i-th criterion;

I – number of partial criteria;

k_i^0 – coefficient of rationing absolute values of partial criteria.

Normalisation solves the task of criteria reduction to uniform scale and dimensionless type by replacement of absolute values of criteria with the relative ones:

$$W_i = \frac{W_i^o}{W_i^{max} - W_i^{min}} \ (i = 1, 2, ..., m), \quad (12)$$

$$W_i = \frac{W_i^o - W_i^{min}}{W_i^{max} - W_i^{min}} \ (i = 1, 2, ..., m), \quad (13)$$

where W_i^{max} is the maximum value of i-th criterion;

W_i^{min} is the minimum value of i-th criterion;

W_i is a relative value of i-th criterion;

W_i^o is a current value of i-th criterion;

m is the number of local criteria.

Then the task of decision-making on handover in heterogeneous wireless networks of mobile communication devices is formulated as follows.

Assume that heterogeneous network consists of M networks of radio access and a set of connections n=1,2..., N. Target function f $(x_{m,n}, r_{m,n}, G_m)$ is an integral criterion which is to be maximised. Each network has limited radio resource G_m and when the user n is distributed into network m, then he uses its resource in the amount of $r_{m,n}$; $x_{m,n}$ is a binary value which equals 1 if subscriber n is distributed into network m, otherwise it equals 0; $res_{m,n}$ is the minimum resource intended to meet requirements of QoS application, N_m is a number of users in network m. When all network resources are occupied but new requests for services are being received, resource allocation between users is carried out according to a certain policy which is represented by function $g_{mn}(v_m, G_m, N_m)$, where:

G_m is the general network capacity;

N_m is the number of users;

v_m is connection characterised by the vector of QoS requirements

The task of decision-making on handover in heterogeneous wireless networks of mobile communication devices can be represented as follows:

$$X^* = \arg\max f\left(X, R, G\right), \quad (14)$$

where $X = \left\langle x_{m,n} \right\rangle$, $R = \left\langle r_{m,n} \right\rangle$, n=1...N, m=1...M; $x_{m,n} \in \{0, 1\}$, $\forall$ n = 1...N, m = 1...M .

Assuming that any mobile communication device either belongs to only one wireless network or it is not connected in general, the following limitation is calculated:

$$\forall n, \sum_{m=1}^{M} x_{m,n} \le 1. \quad (15)$$

The second limitation is defined by limited resource possibilities of networks:

$$r_{m,n} = \begin{cases} res_{m,n}, \ \text{if} \sum_{n=1}^{N} r_{m,n} \cdot x_{m,n} \le G_m; \\ g_{m,n}(\nu_m, G_m, N_m), \ \text{else.} \end{cases} \quad (16)$$

As a method of decision-making on handover it is offered to use the fuzzy logic which has proved as a control device simple in implementation and understanding. Processing (rationing) and aggregation of parameters is carried out with application of fuzzy logic which allows estimation of each parameter by certain linguistic variables, i.e. low, average, high. Each of these variables represents a fuzzy set, membership functions to which are defined on the basis of expert knowledge and experience of users.

Conclusion

Thus the proposed decision-making on handover in heterogeneous wireless networks of mobile communication devices belongs to the class of fuzzy optimisation tasks. Such tasks are characterised by defining part of parameters, limitations and actual target function through subjective user preferences what allows a more complete imitation of decision-making process by the person.

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Поступила в редакцию 23.02.2016, рассмотрена на редколлегии 14.04.2016

ОПТИМІЗАЦІЙНА ПОСТАНОВКА ЗАДАЧІ ПРИЙНЯТТЯ РІШЕНЬ ПРО ПЕРЕДАЧУ ОБСЛУГОВУВАННЯ В ГЕТЕРОГЕННИХ ОДНОРАНГОВИХ САМООРГАНІЗОВАНИХ МЕРЕЖАХ

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Розглянуто сучасні напрямки розвитку бездротових мереж і мобільного зв'язку. Показано, що нові напрямки програмно-обумовленого і когнітивного радіо вимагають формування системи метрик для прийняття рішень про маршрут, або передачі обслуговування в гетерогенних бездротових мережах. На основі аналізу основних виділених метрик сформовано висновок про необхідність застосування різних умов для прийняття вірного рішення. Показано, що рішення про передачу обслуговування в гетерогенних мережах повинно прийматися з урахуванням існуючих різних, суперечливих показників шляхом впровадження єдиної, інтегральної метрики. Запропоновано прийняття рішення про передачу в гетерогенних бездротових мережах мобільних пристроїв зв'язку виробляти за допомогою нечіткої оптимізації.

Ключові слова: бездротова мережа, когнітивне радіо, метрики, якість обслуговування, пристрій мобільного зв'язку, програмно-обумовлена радіосистема, точка доступу.

ОПТИМИЗАЦИОННАЯ ПОСТАНОВКА ЗАДАЧИ ПРИНЯТИЯ РЕШЕНИЙ О ПЕРЕДАЧЕ ОБСЛУЖИВАНИЯ В ГЕТЕРОГЕННЫХ ОДНОРАНГОВЫХ САМООРГАНИЗУЮЩИХСЯ СЕТЯХ

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Рассмотрены современные направления развития беспроводных сетей и мобильной связи. Показано, что новые направления программно-определяемого и когнитивного радио требуют формирования системы метрик для выбора маршрута, либо принятия решений о передаче обслуживания в гетерогенных беспроводных сетях. На основе анализа основных известных метрик сформулирован вывод о необходимости применения множества разнообразных условий для принятия верного решения. Показано, что решение о передаче обслуживания в гетерогенных сетях должно приниматься с учетом существующих различных, противоречивых показателей путем внедрения единой, интегральной метрики. Предложено принятие решения о передаче в гетерогенных беспроводных сетях мобильных устройств связи производить посредством нечеткой оптимизации.

Ключевые слова: беспроводная сеть, когнитивное радио, метрики, качество обслуживания, устройство мобильной связи, программно-определяемая радиосистема, точка доступа.

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