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Research paper

A novel approach for radio resource management in multi-dimensional heterogeneous 5G networks

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Abstract: A GRA-BKP (Grey Relational Analysis-Bounded Knapsack Problem) scheme was proposed for the radio resource management of the 5G networks. It consists of two steps, access selection and admission control. The former step was executed via GRA, whereas the latter problem was formulated as a bounded knapsack problem. Accordingly, an optimal solution of the BKP was given for access selection a greedy algorithm, GRA-Greedy, was proposed for admission control. The simulation results show that the GRA-BKP scheme can effectively increase system profit and decrease the drop-ping probability compared with the existing scheme. In addition, GRA-Greedy achieves comparable perform-ance with the optimal solution GRA-DP, but its computational complexity is much lower than that of the latter.

Key words: access selection, admission control, knapsack problem, greedy algorithm

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1 Introduction

The rising demand for information sharing has resulted in the current communication system facing increasing challenges with respect to capacity, coverage, cost, data rate and latency, etc. Meanwhile, satellite communication systems[1,2] are being considered because of their natural advantages. In this regard, cooperation between systems based in space and existing terrestrial networks, such as LTE, UMTS and WLAN, to provide the voice, video and data service, is foreseen. Especially in the mobile scenarios, for high-speed railway customers, and airplane passengers, a seamless and fluent communication service is strongly desired. For areas largely consisting of dessert or vast stretches of ocean, the high cost of the infrastructure construction and the sparse requirements, means that satellite-based communication would be more affordable and convenient than traditional methods. This is expected to give rise to the formation of a MDHWNC (Multi-Dimensional Heterogeneous Wireless Network) which will be very common in 5G.

Radio resource management[3,4], which is concerned with the distribution of the radio re-source to different users while ensuring user satisfaction, is one of the

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key issues for 5G. Unbal-anced traffic distribution is very likely to happen if the resource of one RAN (Radio Access Network) is managed independently of other RANs. Several distribution schemes have been proposed in recent years. These schemes can be classified according to their beneficiaries, i.e., there are user-centric, network-centric and collaborative approaches. For the user-centric schemes, such as AHP&GRA[5,6] or policy-based schemes[7], users always make decisions based on their preferences or given rules without considering network load balancing or other users[8]. Therefore, this type of scheme mostly focuses on network selection whereas network-centric schemes, such as SLP[4] or schemes based on game theory[9],focus on certain parameters, such as Fuzzy Logic[10] and TOPSIS[4], take the interests of both user and network into account for making decisions; how-ever these schemes are usually complicated. When the number of metrics increases, the system may become very complex and produce erroneous results.

In this paper, a two-step approach, the GRA-BKP, is proposed for the radio resource management of MDHWNs. Access selection is executed by users to choose a proper RAN through the GRA method, and then the network side carries out admission control to admit users, which is modeled as a BKP. The optimal solution of the BKP can be obtained by DPC Dynamic Programming, which is complex and time-consuming.

Therefore an approximation algorithm, Greedy-BKP, is proposed. Accordingly, GRA-DP and GRA-Greedy are the two solutions of GRA-BKP. The simulation results show that the GRA-DP and GRA-Greedy algorithms significantly improve the performance compared with the GRA only approach. Besides, the performance of the GRA-Greedy algorithm is comparable with that of GRA-DP, but its computational complexity is much lower. Therefore, the practical applicability of GRA-Greedy exceeds that of existing schemes.

2 The proposed GRA-BKP scheme

Fig.1 illustrates the overall procedure of the radio resource management in heterogeneous wireless networks. It consists of two key steps, i.e., access selection and admission control.

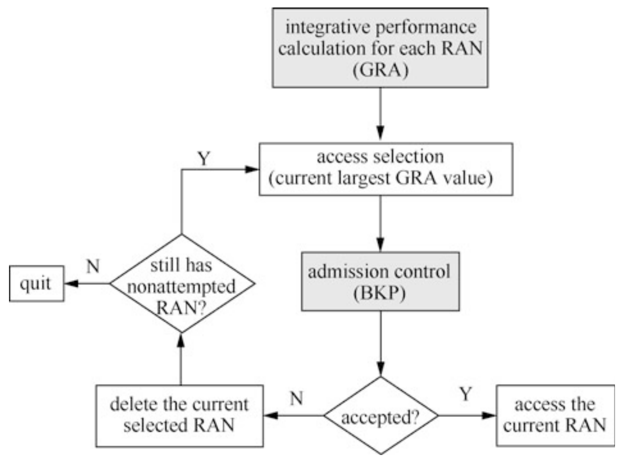

Figure 1 The procedure of GRA-BKP: Access selection is obtained through the GRA method. Each user always tries to access the network with the best integrative performance. On the network side, admission control is executed through BKP. Following this two-step approach, users will be admitted in terms of their preference.

Access selection: When a new user is performing access selection, the system takes factors such as data rate, cost, price, and service into consideration, and assigns different preferences to these factors. Therefore, all the available RANs are sorted based on these multilateral factors, and each user is inclined to choose the one with the best integrative performance. Among the existing access selection schemes, GRA[11] is an effective approach to order RANs.

Admission control: Admission control is processed on the network side. When a network receives several resource requests simultaneously, it has to decide that which one(s) need to be admitted in terms of the limited resource. Previous work has shown that this problem can be modeled as a KP (Knapsack

Problem), but no particular design is reported[12]. In this letter, we maximize the system profit, by modeling the admission control problem as a BKP, which is a variant of KP.

The solution of BKP causes some users to be accepted whereas others are rejected by approaching other RANs. The attempt terminates once the user is either admitted by a RAN or could not be accepted by any RAN.

2.1 Access selection by GRA

Each user compares the available RANs interms of three aspects: QoS, price, and service score.

The QoS parameters consist of the contain transmission rate α Mbit/s, delay ζ ms, response time η ms, jitter θ ms, BER λ dB, burst BER μ, average retransmission times of each packet v, security σ, and service cost ε mA (indicating the cost of the energy). Among the nine factors (N=9), only α and σ are larger-the-better factors, and the rest are smaller-the-better factors.

Let $\boldsymbol{M}$ denotes the number of the available RANs. Let X_{ij} represents the value of the j th $(1 \leqslant j \leqslant N)$ factor of RAN i $(1 \leqslant i \leqslant M)$ for user u. Its normalized value x_{ij} is obtained by Eq.(1) or Eq.(2).

For larger-the-better factors,

$$x_{ij} = \frac{X_{ij} - (X_{ij})_{\min}}{(X_{ij})_{\max} - (X_{ij})_{\min}} , \tag{1}$$

and for smaller-the-better factors,

$$x_{ij} = \frac{(X_{ij})_{\max} - X_{ij}}{(X_{ij})_{\max} - (X_{ij})_{\min}} , \tag{2}$$

where $(X_{ij})_{\min}$ and $(X_{ij})_{\max}$ are the minimal and maximal value of the j th factor of RAN i respec-tively. Let x_{0j} be the standard series of the j th fac-tor. For larger-the-better factors, x_{0j}=1, and x_{0j}=0 for smaller-the-better factors. Then the GRC (Grey Relational Coefficient) is obtained by

$$\gamma_{ij} = \frac{\Delta_{\min} + \Delta_{\max}}{\Delta_{0i}(j) + \Delta_{\max}}, \tag{3}$$

where

$$\begin{aligned} \Delta_{0i}(j) &= | x_{0j} - x_{ij} |, \\ \Delta_{\min} &= \min_{\forall i} \min_{\forall j} | x_{0j} - x_{ij} |, \\ \Delta_{\max} &= \max_{\forall i} \max_{\forall j}{}_{\forall j} | x_{0j} - x_{ij} |. \end{aligned} \tag{4}$$

Let $x_{u,i,q} \sum_{j=1}^{N} \beta_j \times \gamma_{ij}$ be the GRA value of RAN i on QoS, where β_j[5] is the weight for the j th QoS factor, and $\sum_{j=1}^{N} \beta_j = 1$.

For the price and service score, their GRA values can be obtained similarly. The results are denoted as $x_{\mu,i,p}$ and $x_{\mu,i,s}$.

Then the integrated value is acquired by

$$\Gamma_{u,i} = W_{u,q} \times x_{u,i,q} + W_{u,p} \times x_{u,i,p} + W_{u,s} \times x_{u,i,s} \, . \tag{5}$$

where $W_{u,q}+W_{u,p}+W_{u,s}=1$, but each value is dependent on the user preference. Therefore, the RAN with the largest $\Gamma_{u,i}$ will be the optimal decision.

2.2 The new model for admission control

Let the network be a knapsack, and its capacity c the RRUs (Radio Resource Units)[13] it holds. User i's weight corresponds to the resource it requires, and its profit p_i is the income that the network obtains from the service. Unlike the existing method[12], we consider users with the same QoS level demand as items of a kind, thus, the number of users with this level requirement is the number of this item set. Therefore, the admission control problem can be formulated as a BKP (Bounded Knapsack Problem).

$$\begin{aligned} &\max \sum_{i=1}^{n} p_i \times x_i, \\ &\text{s.t.} \sum_{i=1}^{n} w_i \times x_i \leqslant c, \\ &0 \leqslant x_i \leqslant b_i, i = 1, 2, \cdots, n. \end{aligned} \tag{6}$$

In Eq.(6), b_i is the user number with the i th QoS level requirement and n corresponds to the number of QoS level numbers the system affords. The solution indicates the number of users who can be admitted on each QoS level.

1) The optimal solution of BKP: An effective Improved-DP (Dynamic Programming) algorithm to obtain the optimal solution of BKP was proposed[14]. It is a variant of DP for a general KP. The authors showed the Improved-DP solves BKP in $O(nc)$ time and $O(nc)$ memory space, which depends on the size of the capacityand the number of QoS levels the system affords. In fact, it is really not necessary to spare no effort to find an optimal solution of the KP. Instead, a "good" solution would be quite good especially if it could be computed in reasonable time. An approximation algorithm is then proposed to obtain the approximate solution in a reasonable time.

2)The greedy algorithm of BKP: The basic principle of the greedy algorithm is to always pack the knapsack with the highest profit while consuming the lowest amountof capacity.

The efficiency of an item i is defined as

$$e_i := \frac{p_i}{w_i}. \tag{7}$$

Algorithm 1 Greedy algorithm for BKP: Greedy-BKP

$\tilde{w}$:=0 $\tilde{w}$ is the total weight of the currently packed items
Z^G:=0 Z^G is the profit of the current solution
for i:=0 to n do
  if $w + b_i \times w_i \leqslant c$ then
$x_i = b_i$ put all b_i copies into the knapsack
$\tilde{w} = \tilde{w} + b_i \times w_i$
  $Z^G := Z^G + b_i \times p_i$
 else
  $x_i = b_i$
  while $\tilde{w} + b_i \times w_i \geqslant c$ do
   $x_i := x_i - 1$
  end while
$\tilde{w} := \tilde{w} + x_i \times w_i$ put x_i copies of i into the knapsack
  $Z^G := Z^G + x_i \times p_i$
  end if
end for

The greedy algorithm packs items in de-creasing order of efficiency until items can no longer be packed into anymore. The detailedpro-cedure is shown in Algorithm 1, and termed as the Greedy-BKP.

It can be seen that the intension is to pack all copies of each iteminto the knapsack. Otherwise, the tentative number is decreased by one until the capacity constraint is no longer violated. Obviously, each kind of item is considered at most maxbi times,therefore, Greedy-BKP solves $O(n \times \max\ b_i)$ time andO(max b_i) memory space, which is quite low compared to Improved-DP.

3 Simulations

As shown in Fig.2, there are three types of RANs, LTE, WLAN and a Satellite Communications (terms as SatCom). We assumed that the SatCom achieves coverage by either using several LEO satellites or a single GEO satellite, detail of which is beyond the scope of this paper. The RANs have different coverage areas. Only the resource management in the common area is considered, which means that all users in this area have three RANs from which to choose.

According to 3GPP standards[15], the percentage of the four types of traffic, voice, stream, the interactive

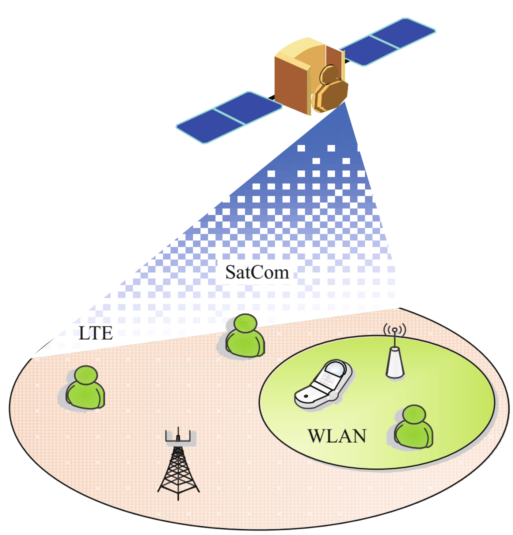

Figure 2 System model

and the background occur in the ratio 3:2:1:4, and in the ratio 7:3 for the real-time and the best-effort traffic. The system affords four QoS levels, which are 2 Mbit/s, 10 Mbit/s, 50 Mbit/s and 100 Mbit/s from QoS1 to QoS4 in terms of the data rate. The types of traffic that each RAN can afford are listed in Tab.1.

Table 1 QoS levels that each RAN can provide (1 indicates that the corresponding level can be provided, otherwise it is 0)

	QoS1	QoS2	QoS3	QoS4
WLAN	0	1	1	1
SatCom	1	1	0	0
LTE	1	1	1	1

The values of each QoS parameter for the three RANs are provided in Tab.2[5].

The price and service score values(i.e., a kind of public praise, for which the full mark is 10) are provided in Tab.3[1].

Tab.4 shows the profit and the weight values attained and occupied by different QoS levels. The values in Tab.3 and Tab.4 are based on the data of the China Mobile Communications Corporation[1].

The following result is the average of 50 times simulation of 100 users. The capacity of WLAN, LTE and SatCom is set as c_W=30, c_S=80, and c_L= 120 respectively, and the unit are their ownRRUs. We compare the result of GRA and GRA-DP, GRA-Greedy.

Table 3 Price and service parameters for each QoS level of each RAN

		price($)	score
W	QoS2	1	6
	QoS3	2	8
	QoS4	4	7
S	QoS1	1	6
	QoS2	3	7
L	QoS1	0.5	7
	QoS2	1	7
	QoS3	3	8
	QoS4	5	9

Table 4 Profit and weight parameters for each QoS level of each RAN ("–": TheRAN cannot provide this service level)

		QoS1	QoS2	QoS3	QoS4
W	*p*($)	–	0.4	1	2
	w(RRU)	–	3	5	9
S	*p*($)	1	1.5	–	–
	w(RRU)	1	3	–	–
L	*p*($)	0.1	0.3	0.8	2
	w(RRU)	1	2	4	8

Fig.3 shows the system profit of the three schemes. Due to the introduction of the admission control, GRA-DP and GRA-Greedy earn a larger profit than GRA, which takes no system profit into consideration. Compared to the optimal solution by GRA-DP, the profit of GRA-Greedy is lower.

Table 2 QoS parameters for each QoS level of each RAT (W: WLAN, S:SatCom, L:LTE)

		α	ζ	η	θ	λ	μ	ν	σ	ε
W	QoS2	10	30	30	10	10^{-5}	0.25	0.2	9	0.2
	QoS3	50	20	20	10	10^{-5}	0.2	0.3	10	0.4
	QoS4	100	15	15	10	10^{-5}	0.25	0.3	10	0.5
S	QoS1	2	50	50	5	10^{-3}	0.5	0.5	9	0.8
	QoS2	10	50	50	5	10^{-3}	0.5	0.5	12	1
L	QoS1	2	20	20	10	10^{-5}	0.25	0.2	10	0.3
	QoS2	10	20	20	10	10^{-5}	0.25	0.2	10	0.3
	QoS3	50	15	15	10	10^{-5}	0.2	0.2	10	0.5
	QoS4	100	10	10	10	10^{-5}	0.25	0.3	12	0.8

1 http://10086.cn/gotone/.

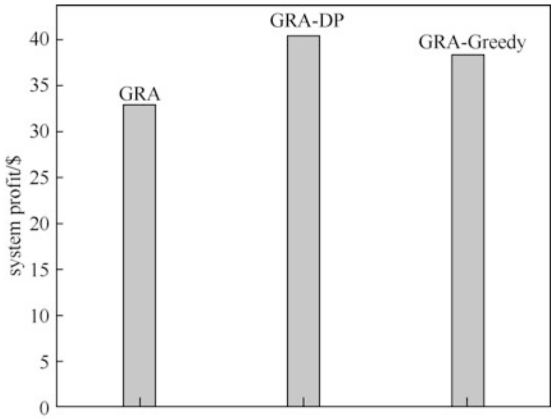

Figure 3 Comparison of the system profit

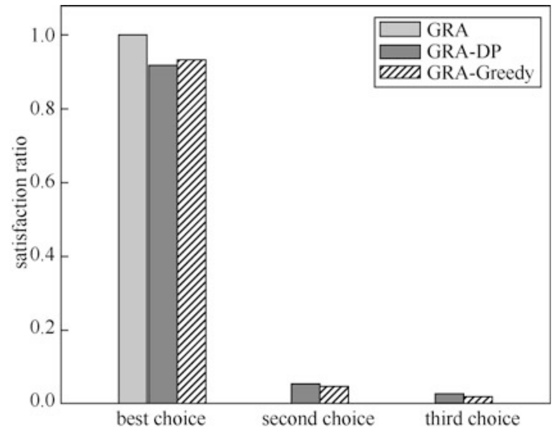

Figure 5 Comparison of the satisfaction ratio

Dropping probability is another important indicator of the scheme. Fig.4 displays the dif-ference among the three schemes. Obviously, GRA appears to have the largest dropping probability. For the two GRA-BKP methods, admis-sion control is based on the user selection. However, even if one user is rejected by its best choice, it will continue to try the second or even the third choice until it can be admitted to the network.This mechanism ensures that the network admits as many users as possible.

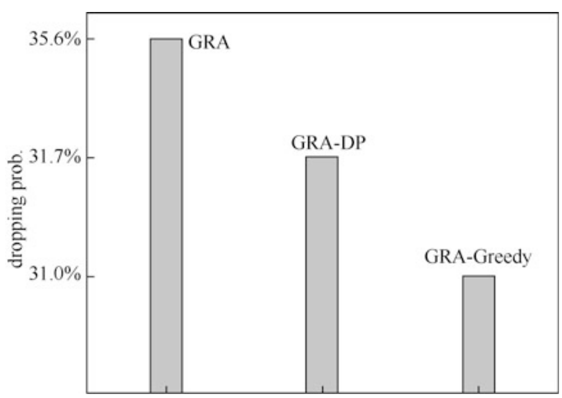

Figure 4 Comparison of the dropping probability

Fig.5 presents a comparison of the satisfac-tion ratio among the three schemes. The three values are defined as the number of served users with the best choice, the second choice, and the third choice divided by the total number of users, respectively.

Users of GRA persist with their best choices, thus the resource may be wasted. However, for GRA-DP and GRA-Greedy, users continue to try other choices; therefore, the second and third choice ratios are nonzero. GRA-Greedy even shows a larger ratio for the best choice.

4 Conclusion and future work

In conclusion, a novel radio resource management scheme was designed for the multidimensional 5G networks. Besides access selection by GRA, we map the admission control problem to a BKP, and proposed GRA-Greedy to obtain quite a fine result. Simulations were carried out to show the excellence our scheme in comparison to existing schemes.

In the future, we plan to take beam, bandwidth, and the mobility of the satellites into con-siderationto continue our research in this area.

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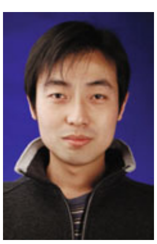

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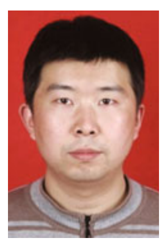

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