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Fitness Landscape Analysis for Scalable Multicast RRM Problem in Cellular Network

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Abstract

This paper aims to solve the Radio Resource Management (RRM) problem for Multimedia Broadcast Multicast Service (MBMS) system in cellular network. We develop a flexible model to perform dynamic radio resource allocation for MBMS service by using metaheuristic approach. We conduct fitness landscape analysis to study the characteristics of the proposed model, which helps us to select appropriate search strategy. Simulation results show that the proposed algorithm provides better performance than existing algorithms.

Keywords: fitness landscape, metaheuristic approach, multimedia multicast, radio resource management.

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1 Introduction

The MBMS service over UMTS could be carried by PTM or PTP mode in a base station. A cell is defined to be the geographic coverage of a UMTS base station. In PTM mode, service is transmitted by a forward access channel (FACH) covering the whole cell. Each FACH needs one channel code serving large amount of users, but may waste power when users are close to the base station [4]. The PTP mode uses dedicated channel (DCH) or shared channel (HS-DSCH). Each DCH needs one channel code serving one dedicated user. A HS-DSCH occupies up to 15 channel codes. PTP mode is more efficient than PTM but the served user number is limited. In UMTS where the radio resources (transmit power and channelization codes) are limited, the transmission mode selection is crucial. To improve the efficiency, **MBMS Power Counting (MPC)** [2] proposes to switch from PTP to PTM when pre-estimated power exceeds an operator-defined threshold, and vice versa. MPC is simple to implement but has very limited flexibility since it does not consider multimedia scalability. **Dual Transmission Mode (DTM)** allows the mixture of PTP and PTM mode for a same service [5]. However, simulation shows that it is only beneficial for up to 5 users [10]. **Scalable FACH Transmission (S-FACH)** [6] transmits scalable encoded service through PTM mode. Services are divided into single layer (SL) and multiple layer (ML) transmission schemes, the latter is divided into several flows. The basic flow is transmitted with lower bit rate while the advanced flows with smaller but fixed geographical coverages. However, S-FACH is still based on the fixed coverage so that the resource allocation can not be optimal.

Consider the quite dynamic property of the RRM problem, all mentioned existing approaches provide only limited flexibility. Therefore, the power and data rate allocation can not be optimal. To address this problem, we propose a Flexible Radio Resource Management Model (F2R2M) by using metaheuristic approach. This model combines two objectives: to satisfy the QoS requirement of multicast service and to minimize the power consumption while avoiding saturation of channel code occupation. To understand the behavior of the proposed model, we conduct fitness landscape analysis on the model under five different scenarios. Based on the analysis results, we evaluate two search operators, and compare the performance with existing approaches.

This paper is structured as follows. The proposed model is formulated in [section 2](#). The fitness landscape analysis and the simulation results are given in [section 3](#). The conclusion is drawn in [section 4](#).

2 Model Description

We focus on multicast transmission within one cell c , which is the geographic coverage of a base station. The input variables are defined as follows: $T(c) = \{t_1, \dots, t_{Nt}\}$ is a set of users located in c , and their instantaneous geometry coordinates $C(c) = \{(x_1, y_1), \dots, (x_{Nt}, y_{Nt})\}$. A set of services $S(c) = \{s_1, \dots, s_{Ns}\}$ and their the flows $F(s_i) = \{f_{s_i,0}\}$ or $\{f_{s_i,1}, f_{s_i,2}[f_{s_i,3}]\}$ are transmitted in c . $f_{s_i,0}$ indicates s_i is SL transmission scheme. $f_{s_i,j}(j > 0)$ is the sublayers of ML scheme service, $f_{s_i,1}$ is the basic flow and $f_{s_i,j}(j > 1)$ is the advanced flow which is optional for quality improvement. Each user group subscribing to the same service is called a multicast group: $Dist(s_i) = \{t_n, t_m, \dots\}$.

F2R2M supports the co-existing of PTM and PTP modes for each flow. It partitions $Dist(s)$ into four disjointed sets: users served through a FACH $UE_{fach}(f_{s,j})$; users transferred through DCHs $UE_{dch}(f_{s,j})$; users sharing HS-DSCH $UE_{hs}(f_{s,j})$ and non-served users $UE_{noch}(f_{s,j})$. The decision of user set follows two principles: 1) to guarantee the service coverage, all users in multicast group should be selected to receive $f_{s_i,0}$ or $f_{s_i,1}$, 2) in ML transmission, the advanced flow is sent only when a lower flow has been received by users. The partition of user depends on channel characteristics: 1) FACH can be listened by all users within its coverage, hence $UE_{fach}(f_{s,j})$ includes the nearest group of users in $Dist(s)$, with the distance from the base station under a threshold d_{thr} . d_{thr} is dynamically determined during search procedure. 2) the users in $Dist(f_{s,j})$ farther than d_{thr} , are assigned to $UE_{dch}(f_{s,j})$ or $UE_{hs}(f_{s,j})$. Consequently, according to the user partition and flow bandwidth, available channel code(s) is associated with a nonempty user set. When no channel code is available for a given user, this user is switched to $UE_{noch}(f_{s,j})$.

A solution is defined as variable x , which is a matrix with Nt (number of flows) rows and Nf (number of users) columns:

$$x = \begin{matrix} & f(s_1,1) & f(s_1,2) & \dots & f(s_{Ns},0) \\ \begin{matrix} t_1 \\ \dots \\ t_i \\ \dots \\ t_{Nt} \end{matrix} & \begin{pmatrix} ch_{1,1} & ch_{1,2} & \dots & ch_{1,Nf} \\ \dots & \dots & \dots & \dots \\ ch_{i,1} & ch_{i,2} & \dots & ch_{i,Nf} \\ \dots & \dots & \dots & \dots \\ ch_{Nt,1} & ch_{Nt,2} & \dots & ch_{Nt,Nf} \end{pmatrix} \end{matrix}, ch_{i,j} \in \{-1, 0, 1, 2, 3\}$$

$x(i,j)$ indicates the channel allocation of user t_i for flow f_j . Values 0, 1, 2, 3 represent four possible user allocations: $UE_{noch,fach,dch,hs}(f_{s,j})$. -1 means the user does not belong to the multicast group. Hamming distance is used to measure the distance of two feasible solutions, which will be used in the calculation of indicators for fitness landscape analysis.

The power consumption is implicitly determined once user and channel code allocation are determined. As simulated in [1], P_{FACH} can be got through

a look up table based on the user distribution in $UE_{\text{fach}}(f_{s,j})$. The DCH transmission power for n users [9] is calculated by : $P_{\text{DCH}} = \frac{P_p + \sum_{i=1}^n Lp_i \cdot \frac{P_n + I_i}{(E_b/N_o)R_{b,i} + p}}{1 - \sum_{i=1}^n \frac{p}{(E_b/N_o)R_{b,i} + p}}$,

where P_p is common control channel power, P_n is the background noise, Lp_i is user path loss, W is the bandwidth in UMTS, $R_{b,i}$ is the transmit rate of i th user, p is the orthogonality factor, I_i is the intercell interference observed by i th user. The transmit power to guarantee the required HS-DSCH throughput [8] is: $P_{\text{HS-DSCH}} \geq \text{SINR} \times [p - G^{-1}] \frac{P_{\text{own}}}{16}$, in which P_{own} is the own cell interference experienced by user, G is the geometry factor defined by $G = \frac{P_{\text{own}}}{P_{\text{other}} + P_{\text{noise}}}$, related with the user position.

A two-dimensional fitness value $F(x) = \{Th(x), Po(x)\}$ is defined to measure the solution quality. $Po(x)$ is the MBMS transmission power: $Po(x) = \sum_{s_i \in S(c)} \sum_{f_j \in F(s_i)} \sum_{ch_l} P_{f_j, ch_l}$. $Th(x)$ is the throughput loss in cell: $Th(x) = \sum_{s_i \in S(c)} \sum_{f_j \in F(s_i)} \sum_{t_u \in Dist(f_{s_i, j})} \max[-\Delta_{j,u}, 0]$. $\Delta_{j,u}$ is the difference between allocated channel bit rate (determined by its channel code(s) [3]) and flow bandwidth. The optimization target is to first satisfy the throughput requirement within the maximum power budget, then to minimize the transmission power. Therefore, the comparison of a new solution x' and current solution x is conducted in lexicographic order: x' is evaluated as a better solution when $Th(x') = Th(x)$ and $Po(x') \leq Po(x)$, or $Th(x') < Th(x)$.

We propose two operators to move solution into a neighbor solution.

- **Hybrid-moves operator** δ_H randomly selects user t_k from a non-empty $UE_{\text{cho}}(f_{s,j})$, then t_k or a block of users including t_k is moved from $UE_{\text{cho}}(f_{s,j})$ to $UE_{\text{chi}}(f_{s,j})$. The moved users depends on the chosen set. For example, if ch_i is FACH, the coverage is enlarged to t_k , all the users nearer than t_k can now hear from FACH, thus, no matter what user sets they are currently allocated at, they should stay or be inserted in $UE_{\text{fach}}(f_{s,j})$.
- **Insert operator** δ_I moves only one user for each operator application. Once it chooses FACH as ch_i or ch_o , then t_k is determined: the nearest user in $UE_{\text{hs}}(f_{s,j}) \cup UE_{\text{dch}}(f_{s,j}) \cup UE_{\text{noch}}(f_{s,j})$, or the farthest user within $UE_{\text{fach}}(f_{s,j})$.

3 Fitness Landscape of F2R2M

In Table 1, five test scenarios with different service configurations and user numbers are designed for simulations. For example, in the first scenario $2s-50-sn$, two services s_1 and s_2 are transmitted to 30 and 20 users respectively. s_1 consists of three flows: f_1, f_2 at 32 kbps, and f_3 at 64 kbps. s_2 consists of only

one flow f_0 at 128 kbps. The users are assumed to be uniformly distributed around the base station.

Table 1
Simulation scenarios

Scenarios	Service number, Flow bandwidth	User number per service
scen 1: 2s-50u-sn	2, $s_1(f_1, f_2 : 32kbps, f_3 : 64kbps); s_2(f_0 : 128kbps)$	30,20
scen 2: 2s-50u-ss	2, $s_1(f_1, f_2 : 32kbps, f_3 : 64kbps); s_2(f_1, f_2 : 64kbps)$	30,20
scen 3: 3s-80u-snn	3, $s_1(f_1, f_2 : 32kbps, f_3 : 64kbps); s_2(f_0 : 128kbps); s_3(f_0 : 64kbps)$	30,20,30
scen 4: 3s-80u-ssn	3, $s_1(f_1, f_2 : 32kbps, f_3 : 64kbps); s_2(f_1, f_2 : 64kbps); s_3(f_0 : 64kbps)$	30,20,30
scen 5: 3s-100u-ssn	3, $s_1(f_1, f_2 : 32kbps, f_3 : 64kbps); s_2(f_1, f_2 : 64kbps); s_3(f_0 : 64kbps)$	30,40,30

In our model, two fitness landscapes L_{hy} and L_{in} are defined by δ_H and δ_I . We study their characteristics in three aspects: 1) the distribution of feasible solutions within search space; 2) the distribution of fitness space; and 3) the links between distance and fitnesses of solutions. Two populations of solution S_{ini} and S_{lo} are generated. S_{ini} is composed of 600 solutions randomly chosen from the initial solution space. S_{lo} is the population of local optima found by applying hill climbing (HC) [7] to S_{ini} . Starting from a random solution in S_{ini} , HC evaluates all its feasible neighbors and replaces it by the neighbor that has the best fitness. HC stops at S_{lo} when no neighbor is better than current solution.

3.1 Analysis of Search Space

To study the distribution of feasible solutions in search space, two types of distance are calculated: d_{ini} and d_{lo} are the distances among any two solutions in S_{ini} and S_{lo} . Table 2 presents the minimum, the maximum and the quartiles

Table 2
Analysis of Search Space: distance between solutions of landscapes

	$L_{in} : d_{ini}$ in $S_{ini,in}$			$L_{in} : d_{lo}$ in $S_{lo,in}$			$L_{hy} : d_{ini}$ in $S_{ini,hy}$			$L_{hy} : d_{lo}$ in $S_{lo,hy}$		
	Min	Quartiles	Max	Min	Quartiles	Max	Min	Quartiles	Max	Min	Quartiles	Max
scen 1	15	62 _{54,72}	109	17	62 _{54,71}	108	19	62 _{53,71}	108	0	34 _{23,45}	109
scen 2	20	64 _{55,74}	114	20	65 _{55,75}	117	23	64 _{54,73}	121	0	33 _{22,46}	127
scen 3	20	64 _{55,73}	116	20	64 _{55,74}	116	21	65 _{54,73}	115	0	43 _{30,57}	138
scen 4	26	66 _{56,76}	148	20	66 _{56,76}	148	20	64 _{55,73}	116	0	35 _{24,49}	156
scen 5	21	64 _{55,73}	130	19	65 _{55,76}	180	21	64 _{55,73}	129	0	38 _{23,56}	194

(median, Q1 and Q3) of these distances. Firstly, for both operators, the distance statistics in the initial solution space (d_{ini} in $S_{ini,in}$ and $S_{ini,hy}$) are homogeneous, that is simply because they are randomly selected in the initial

solution space. Secondly, when looking at the the distance statistics in the local optima space (d_{lo} in $S_{lo,in}$ and $S_{lo,hy}$), δ_H generates much converged space.

3.2 Analysis of Fitness Space

Figure 1 illustrates the fitness value distribution of S_{ini} and S_{lo} for the fifth scenario $3s-100u-ssn$. The fitness values of S_{ini} are well diversified for both operators. Comparing the first and third subfigures, the quality of $S_{lo,hy}$ is

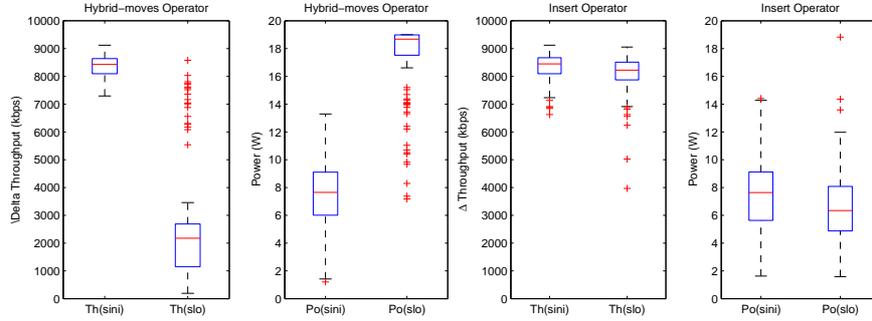


Fig. 1. Analysis of Fitness Space: Comparison of two fitness space (3s-100u-ssn)

better than that of $S_{lo,in}$ ($Th_{hy}(lo) < Th_{in}(lo)$). The same situation for the other scenarios is confirmed in Table 3, in which we can see δ_H finds solutions with smaller $Th(x)$, hence better solutions than δ_I . This can be explained by the fact that, unlike δ_I , δ_H moves a block of elements which explores larger search space, so that it can easily escape from the local optimal.

Table 3

Fitness space analysis: fitness values of populations of local optima

Scenarios	Fitness	$L_{hy}: S_{lo,hy}$				$L_{in}: S_{lo,in}$			
		Min	MedQ1,Q3	Max	Mean	Min	MedQ1,Q3	Max	Mean
2s-50u-sn	Th(x) %	0	0 _{0,0}	58	1.7	4.5	57.5 _{52.25,62}	69	56.21
	Po(x) w	7.08	14.89 _{12.95,18.18}	19.0	15.28	1.5	6.53 _{5.03,8.33}	18.54	6.44
2s-50u-ss	Th(x) %	0	0 _{0,0}	62.5	0.94	0	58.75 _{54,62}	69.5	10.74
	Po(x) w	5.81	14.63 _{14.36,15.02}	16.58	14.57	1.69	6.24 _{4.69,7.93}	16.3	6.44
3s-80u-snn	Th(x) %	0	4 _{0,15}	91.5	9.43	37	87.5 _{82,92}	99	86.61
	Po(x) w	5.543	17.29 _{15.92,18.79}	18.99	17.2	2.10	6.56 _{4.96,8.21}	18.96	6.74
3s-80u-ssn	Th(x) %	0	1 _{0,2}	93.5	3.8	20.5	88 _{83.5,91.5}	99	86.34
	Po(x) w	6.38	17.57 _{17.22,17.63}	19.0	17.2	2.1	6.56 _{4.96,8.21}	18.96	6.75

3.3 Analysis of Links between Distance and Fitness

In F2R2M, step length is the number of implemented operator applications by using hill climbing method. The average step length in L_{hy} for five scenarios are: 26, 27, 43, 68, 100. While in L_{in} , they are: 10, 10, 9, 11, 13. In general, δ_I moves shorter distance than δ_H , which makes the search procedure walks nearby the initial solution. This explains that the search space of $S_{lo,in}$ does not concentrate the $S_{ini,in}$ (Table 2). Therefore, L_{in} is “shallower” than L_{hy} .

3.4 Results Comparison with Conventional Algorithms

The solutions of competing approaches and the best found solutions based on F2R2M are shown in Table 4. Solutions are represented in two-dimensional: $Th(x)$ in percentage and $Po(x)$ in watts. The maximum power budget is set as 19w hence solutions with $Th(x) < 19$ are feasible and emphasized in boldface. Both operators in F2R2M can always find good enough solutions: less throughput loss with less power consumption than existing approaches. The mean fitness values of found solution with F2R2M-in for scenarios 2 to 5

Table 4
Results comparison with existing approaches

Scenarios	MPC { $Th(x), Po(x)$ }	DTM { $Th(x), Po(x)$ }	S-FACH { $Th(x), Po(x)$ }	F2R2M-in { $Th(x), Po(x)$ }	F2R2M-hy { $Th(x), Po(x)$ }
2s-50u-sn	0%,27.2	0%,30.5	65% 10.2	4.5%, 18.5	0% 10.2
2s-50u-ss	0%, 27.2	0%, 30.5	47% 15.4	0%,15.58	0% 13.1
3s-80u-snn	0%, 32.5	0%,37.7	25.4% 27.0	25.4%, 16.9	0% 15.0
3s-80u-ssn	0%, 32.5	0%,37.7	36.2% 22.6	15.4%, 16.5	0% 14.4
3s-100u-ssn	0%, 37.73	0%,37.69	51.18%,15.9	15.9%,18.12	1.76%,17.5

are from (56.2%, 6.4 w) to (74.4%, 6.65 w) with standard deviation from (8.12, 2.45) to (7.13, 2.55). While for F2R2M-hy, the mean fitness values are from (1.7%, 15.3 w) to (7.29%, 18.12 w) with standard deviation from (8.2,2.56) to (11.93, 1.4). δ_H performs better than δ_I , which proves the discussion in section 3 that δ_H has capacity of “jump” from bad solutions, while δ_I can only stay in basins. Besides, the average consuming time of one HC trial is calculated, δ_I and δ_H needs 0.06s and 0.16s for 2s-50u-sn, 0.77s and 0.31s for 3s-100u-ssn. Both operators can find good enough solution with acceptable time. δ_H can move more steps hence farther than δ_I , therefore the hybrid-moves operator costs double time than insert operator.

4 Conclusion and Perspective

In order to solve the RRM problem in MBMS system, we propose a novel model named Flexible Radio Resource Management Model (F2R2M) using metaheuristic approach. In our model, two objectives are taken into account to satisfy the QoS request and minimize the power consumption. Based on fitness landscape analysis, a study is investigated on the performance of the two proposed neighborhood functions. Simulation results show that our approaches can achieve significant gains comparing with the other existing approaches. In the future work, we are interested in applying the other local search algorithms such as Simulated Annealing and Tabu Search to improve the search efficiency.

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