

Analysis of traffic offload using multi-attribute decision making technique in heterogeneous shared networks

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Abstract: Over the years, the authors have witnessed tremendous growth in mobile data traffic. To address the capacity requirements, the mobile network operators (MNOs) are adding more radio nodes and spectrum layers. The spectrum layers vary in quality of service (QoS), utilisation and usage fee. To save operational costs, the MNOs could share their radio networks. The MNOs, therefore, should consider spectrum availability, link utilisation, link usage costs, traffic handling priorities and QoS for selecting the Donor link for traffic offload. In this study, the traffic offload scenario with multiple Donor links from different MNOs is analysed. The authors define the relevant queuing parameters for Donor link selection. Two hybrid multi-attribute decision-making (MADM) techniques, namely, (a) analytical hierarchical process (AHP) with grey relational analysis (GRA) technique and (b) entropy with range of values (RoV) technique for dynamic Donor link selection in traffic offload scenario and assess their benefits were compared. The authors use IP network measurements to derive the packet service time. It is observed that both the techniques Entropy-RoV and AHP-GRA align well with the dynamism of the network, though Entropy-RoV method performed without any pre-configuration. The AHP-GRA technique requires pre-configuration of parameters and when configured suitably, it can perform as a load equalisation technique.

1 Introduction

Over the years, we have witnessed tremendous mobile data growth resulting in traffic surges. From [1], we understand that mobile data traffic has grown 18-fold in the last 5 years globally. In the past year, it has grown at ~63% and is expected to increase sevenfolds in the next 5 years. We see similar trend for a developing market like India in [2] where we see the traffic increased ~50–70% each year. To address the burgeoning capacity need, the mobile service providers can create a heterogeneous network by adding multiple spectrum layers and radio nodes. Addition of these spectrum layers are either in licensed spectrum (with usage fees) or unlicensed spectrum (with no usage fees). The latest radio technologies like LTE-Advanced [3], Multefire [4] and 5G New Radio allow flexibility to use both licensed and unlicensed spectrum for traffic offload.

Since the traffic surge could be momentary, scaling-up the network may leave many of the spectrum layers under-utilised. Hence a dynamic load balancing technique is needed to effectively offload traffic on to existing under-utilised links. Further, the mobile operator should consider spectrum availability and usage fees along with quality of service (QoS) and link utilisation for traffic offload.

To save operational costs, the mobile network operators (MNOs) can also share the radio networks. In the sharing scenario, one of the MNO becomes beneficiary/seeker (wishes to make use of its own/another operator's bandwidth) and the other becomes Donor (wishes to offer bandwidth for others to use based on certain conditions). The MNO, therefore, should consider spectrum availability, link utilisation, link usage fees and QoS and for link selection for traffic offload.

Fig. 1a highlights the mobile network sharing scenario. We consider two MNOs A and B sharing their mobile network here. The mobile radio network is a heterogeneous network with pooled radio baseband. The Macro radio radiates two radio carriers (one for each MNO A and B). The low power Micro radio unit (covering hotspot) radiates a third radio carrier for MNO B. The pooled radio baseband or Edge Cloud helps reduce the latency for the offload traffic and the parameter feedback from the Donor links. The mobile radio network is connected to one or more Mobile Core network (one Mobile Core network each for MNO)

over a backhaul link. Mobile Core network is further connected to an IP cloud. In the mobile network considered, MNO A is the Beneficiary/Seeker and MNO B is the Donor. Alternately, the mobile network may be owned by a mobile virtual network operator (MVNO) which can offer capacity/spectrum layers as service to multiple MNOs.

Donor link selection for traffic offload in a multi-MNO heterogeneous network is not straightforward. The Donor link can have different parameters contributing to QoS (link capacity, MNO's traffic handling/scheduling priority, link load), link usage charges, overall link utilisation. Hence, we need a dynamic link selection scheme to select the best option.

In this paper, we analyse from the queuing perspective, the traffic offload scenario with multiple Donor links from different MNOs. We consider the exponential distribution for Beneficiary and Donor link ingress traffic. We consider the multimodal distribution for IP data packet size (based on IP network measurements) and derive packet service time considering bandwidth of each link and the IP packets size.

We define the relevant parameters for Donor link selection. For an MVNO deploying software defined radio based next generation network (NGN), these parameters (for Donor link selection) can be monitored using Cloud infrastructure with virtualisation. We use two hybrid MADM techniques, namely, analytical hierarchical process-grey relational analysis (AHP-GRA) and Entropy-RoV method to select the Donor link in multi-MNO shared network and compare them for different Donor link configurations.

2 System model

We model the system under consideration as a network of links/queues and assume the availability of multiple Donor links for traffic offload. The model has the following functional blocks:

- Beneficiary link* – This refers to radio carrier of Beneficiary MNO. In case of traffic surge, the traffic is offloaded to other Donor carriers/links.
- Donor links* – This refers to under-utilised radio carriers of Donor MNOs who are ready to offer part of the capacity/bandwidth to Beneficiary MNO.

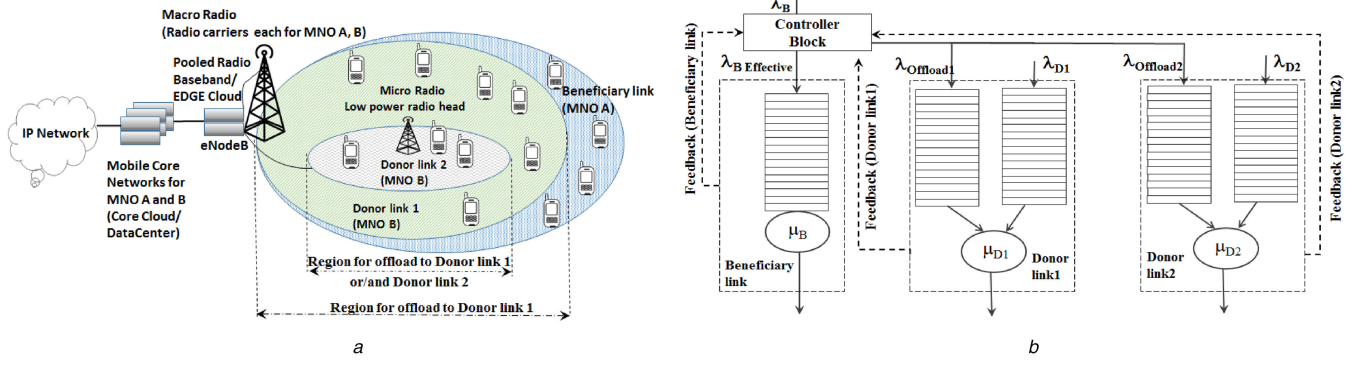


Fig. 1 System model

(a) Network sharing in heterogeneous network, (b) Equivalent queuing model with Beneficiary and Donor links

Table 1 IPv4 packet size distribution

IPv4 packet size, bytes	Frequency, %
40	13
52	23
60	1.3
64	1.3
75	1.1
87	1.5
200	5
1240	1.1
1400	2.4
1464	2
1480	6.6
1500	15.21

(c) *Controller block* – The Controller Block monitors (a) link utilisation of Beneficiary and Donor links and (b) average waiting time experienced by the IP packets in each link and selects the best Donor link for routing the IP packets in case of traffic surge in the Beneficiary link.

(d) *Connectivity between Beneficiary and Donor links* – This carries the offloaded traffic from Beneficiary link to the other Donor links. The Beneficiary–Donor connectivity links are considered without delay.

Each of the Beneficiary and Donor link independently has its ingress traffic. The Beneficiary link has ingress at the rate λ_B and average service time of $1/\mu_B$. For $(\lambda_B/\mu_B) \geq 1$, the Controller Block helps the Beneficiary link to work under saturation and routes the excess traffic (beyond certain threshold) through one of the Donor links.

Each of the Donor links has its own traffic with Poisson arrival times, along with the offload traffic routed from the Beneficiary link. We model Donor links as a non-pre-emptive multi-class priority queue with two classes of service (a) own traffic of Donor link as λ_D and (b) the offload traffic from Beneficiary link as λ_{Offload} . The queuing model considered in this paper resembles a ‘server farm’ model, with Controller Block handling ‘packet assignment policy’ and each of the Donor link handling ‘packet scheduling policy’.

As per [5], the packet-based communication systems can be modelled as an M/G/1 queue. We model the Beneficiary and Donor links, as an M/G/1 FCFS queue. This queue operates under the region of stability ($\lambda < \mu$). The excess ingress traffic (λ_B) above certain threshold is offloaded to the Donor links that is ready to offer part of its server capacity. In this paper, we limit our discussion to non-guaranteed-bitrate traffic.

2.1 Packet size distribution

From [5], we understand that few accumulated points (or modes) dominate the service time distribution of IP-based communication

systems. Hence, the computation complexity may be limited to considering multi-modal distributions for the packet service time. We use IP traffic data measurement from March 2016 [6], which was performed for little over 1 h and with close to 2 billion packets processed. The analysis of the traffic shows 96.4% to be IPv4 data packets. The IPv4 packet size distribution is shown in Table 1.

2.2 Packet service time distribution

Given the average capacity of link is C_k (Mbps), the packet service time T_k for each of the packet arriving at the k th link (Beneficiary and Donor links) is

$$\text{packet service time } T_k = \frac{C_k}{\text{Packet size}_k} \quad (1)$$

where k th link is either a Beneficiary link and Donor link. Packet size is computed with the multimodal distribution using values from Table 1. We consider Beneficiary and Donor links with an average link capacity of 35 Mbps (a value equivalent to average downlink cell throughput of FDD LTE 20 MHz [7]).

2.3 Latency measurement

As per [8], the latency measurement for the user plane traffic at the 3GPP eNodeB node, for a given QoS class, is computed by accumulating delay T , over the measurement period where

$$T = t_{\text{first part of data volume transmitted}} - t_{\text{data received}} \quad (2)$$

The samples are measured as time interval between the reception of IP packet at the node and the time when the node transmits the first block. This is done to achieve a delay measurement that is independent of IP data block size. Each measurement is an integer value representing the time in millisecond (ms). Overall latency (or average waiting time), thus is

$$\text{Latency} = \text{Avg. waiting time} = \frac{\sum T}{\text{Number of samples}} \quad (3)$$

For convenience, we denote the average waiting time by $W_{\text{link}}^{\text{traffic}}$ where *traffic* is λ_B , λ_{Offload} , or λ_D and *link* is Beneficiary, Donor or Overall.

2.4 Simulation framework

Using MATLAB SimEvents as the discrete event simulation framework, both Beneficiary and Donor links are modelled as M/G/1 FCFS queue. Donor link caters to its own IP traffic as well as offloaded IP traffic from the Beneficiary link. The scheduling priority between λ_{Offload} and λ_D in the Donor link is configurable.

For the service time distribution, MATLAB SimEvents module lacks inherent support for the multimodal distribution. Hence, we generate the packets with their sizes following multimodal

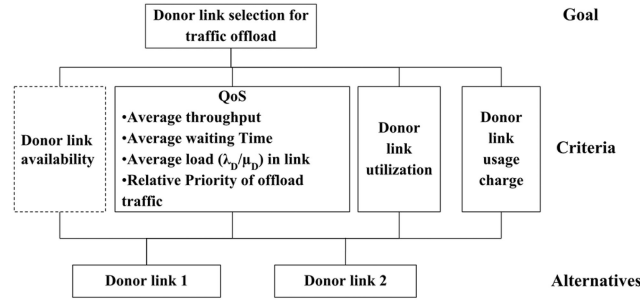


Fig. 2 MADM criteria for Donor link selection

distribution using the distribution given in Table 1. We then compute the packet service time as per (1).

For computing the average waiting time, we note the time of arrival of packet at Ingress, for both Beneficiary and Donor links and the elapsed time at the end of its service (at Beneficiary or Donor links).

3 Donor link selection using MADM techniques

In this section, we introduce hybrid MADM techniques for Donor link selection, in a multi-MNO heterogeneous network. In [9], the authors list the most often used MADM methods for the selection of alternatives and compare them for their usage in Cloud service. In [10, 11], the performance of MADM methods is compared for different traffic types.

In this paper, we evaluate use of combination of MADM methods. This is explained in detail in the following section.

3.1 MADM methods

MADM involves (a) an established goal (b) a set of evaluation criteria and (c) a set of alternatives.

As shown in Fig. 2, we first select the goal as Donor link selection. We define the criteria for Donor link selection to be as follows:

(a) QoS (α) with following sub-criteria

- i. Average Donor link throughput (δ)
- ii. Average Waiting Time of λ_{Offload} in Donor link (ζ)
- iii. Average load (λ_D/μ_D) in Donor link (η)
- iv. Relative priority of λ_{Offload} in Donor link (θ)
- v. Delay in Beneficiary–Donor connectivity (ϵ)
- (b) Average Donor link ($(\lambda_{\text{Offload}} + \lambda_D)/\mu_D$) utilisation (β),
- (c) Average Donor link usage cost (γ)
- (d) Donor Link availability.

We envisage that for an MVNO deploying software defined radio-based NGN, these parameters can be monitored using Cloud infrastructure and used for dynamic link selection. The alternatives in the current context are a set of available Donor links.

The MADM techniques have two stages (a) derivation of weights for each criterion used for selection and (b) ranking of alternatives considering the weights and values of each criterion. In hybrid MADM technique, different MADM methods may be used derivation of weights and ranking of alternatives.

For the derivation of weights, the MADM methods can be classified into

- (a) *Subjective* – where the weights are derived by comparing the importance of one criterion over other, by a Decision Maker or System Engineering expert, e.g. AHP.
- (b) *Objective* – where the weights are derived by comparing the instantaneous data of each criterion, e.g. Entropy.

In this paper, we use hybrid MADM techniques to select the Donor link in multi-MNO shared network.

3.1.1 AHP method: The AHP method, covered in [12], is a tool for solving complex multi-criteria decision problems. In this process, the criteria are analysed, through pairwise rating within a scale of 1–9 as mentioned in [12], to estimate the relative priorities of each of them. Since these pairwise comparisons are subjective, judgment errors are inevitable. Hence, consistency checks are performed by computing the consistency ratio (CR) by first finding the consistency index (CI) of the AHP matrix by

$$CI = (L_{\max} - n)/(n - 1) \quad (4)$$

where n is the dimension of the comparison matrix and $L_{\max}$ is the eigenvalue.

If CI is equal to zero, the matrix is perfectly consistent; otherwise, CI should be positive. CR is computed as

$$CR = CI/RI \quad (5)$$

where RI is random index defined in [12]. The decision matrix is considered acceptable if $CR < 0.1$.

Next, we derive the overall weights by computing the product of weights of each factor and its sub-factor. Hence unified vector of weights for the criteria is

$$W = \{w_1, w_2, w_3, w_4, w_5, w_6\} \quad (6)$$

3.1.2 GRA method: GRA, introduced in [13], is an effective method for analysing relationship of discrete sequences. One of the sequences is determined as a reference sequence indicating ideal or required situation. This forms a data sequence for each of the Donor link, namely $(X_1, X_2, X_3, \dots, X_n)$. Each of these n sequences have say k parameters, i.e. $X_i = (x_i(1), x_i(2), x_i(3), x_i(4), \dots, x_i(k))$, where $i = 1, 2, 3, \dots, n$. Each of the data sequence is normalised as per two criteria, beneficial (larger-the-better, e.g. average throughput), non-beneficial (smaller-the-better, e.g. average waiting time, link utilisation, usage cost).

Assuming ideal sequence X_0 contains the upper bound, lower bound or moderate bound values in the larger-the-better, smaller-the-better and nominal-the-best, grey relational coefficient (GRC) is computed as

$$GRC_i = \frac{1}{m} \sum_{j=1}^m \frac{\Delta_{\min} + \Delta_{\max}}{\Delta_{ij} + \Delta_{\max}} \quad (7)$$

where $\Delta_i = |x_0^*(j) - x_i^*(j)|$, $\Delta_{\max} = \max_{(i,j)} (\Delta_i)$, $\Delta_{\min} = \min_{(i,j)} (\Delta_i)$, and $\max_{(i,j)}()$, $\min_{(i,j)}()$ are functions for computing the maximum and minimum of a set of numbers varying with i and j . The option with higher GRC is considered selected.

3.1.3 Entropy method: In information theory, the concept of entropy from Shannon [14] indicates the average amount of information associated with attribute or sample and acts as a measure of uncertainty. In the domain of MADM, entropy can be used as an objective measure to calculate the weight of attribute [15].

Suppose, we must select an alternative among m candidates and there are n attributes that contribute to make this decision, the normalised attribute matrix is defined as

$$R = (X'_{ij})_{m \times n} \quad (8)$$

The entropy for the attribute j is defined as

$$e_j = \frac{-1}{\ln m} \sum_{i=1}^m f_{ij} \ln f_{ij}, \quad i = 1, 2, \dots, m \text{ and } j = 1, 2, \dots, n \quad (9)$$

where $f_{ij} = X'_{ij} / (\sum_{i=1}^m X'_{ij})$ and $0 < e_j < 1$.

The entropy weight of the attribute j is defined as

$$w_j = \frac{1 - e_j}{\sum_{j=1}^n (1 - e_j)}, \quad j = 1, 2, \dots, n \quad (10)$$

where $\sum_{j=1}^n w_j = 1$.

3.1.4 RoV method: The RoV method was first proposed in [16], and calculates the best and worst utility for each alternative.

Suppose, we must select an alternative among m candidates and there are n attributes that contribute to the decision, the best and worst utility of each alternative is computed as

$$\text{Maximise: } u_i^* = \sum_{j=1}^m X'_{ij} w_j \quad (11)$$

$$\text{Minimise: } u_i^- = \sum_{j=1}^m X'_{ij} w_j \quad (12)$$

such that $w_1 \geq \dots \geq w_m$; $\sum_{j=1}^m w_j = 1$.

The ranking of alternatives is performed considering the midpoint of u_i^* and u_i^- which is computed as

$$u_i = \frac{u_i^* + u_i^-}{2} \quad (13)$$

3.1.5 Hybrid MADM techniques: Combination of MADM methods, e.g. AHP-GRA (AHP method for weight computation and GRA method for ranking) has been applied for network selection from the mobile phone perspective under 'Always Best Connected' design goal [17]. In [18] this hybrid method has been used to select the best possible network connectivity, primarily considering radio channel parameters and the user preferences. In [19], the AHP-GRA method has been used for peer-to-peer link selection for vehicular connectivity. In [20], this method is used to determine switching off small cells (from energy consumption perspective). In [21, 22] this hybrid method has been used for selecting the best network layer for vertical handover.

Individually, the Entropy method has been used in networking domain for packet forwarding strategy in [23]. Similarly, RoV

method has been used in water resource management [24] and for solving cutting fluid selection problem [25].

The combination of Entropy-ROV methods (Entropy method for weight computation and RoV method for ranking) has been evaluated recently in [26] for apple selection problem. This hybrid technique has not been explored for network link selection problem yet.

In this paper, we use and compare two hybrid MADM techniques, namely, AHP-GRA and Entropy-RoV techniques to address the Donor link selection problem for traffic offload scenario in multi operator heterogeneous shared network. The analysis is from queuing standpoint and the network scope.

The overall MADM model has three phases (a) Data Collection (b) Data Processing and (c) Decision Making (Fig. 3).

Data Collection Phase: In this phase, the Controller Block continuously checks the Donor link parameters (a) average waiting time of offload traffic in the Donor link (b) Donor link utilisation and stores them for processing.

Data Processing Phase: The processing in phase is dependent on the combination of MADM methods chosen.

In case of AHP-GRA model, we first compute the relative weights of each criteria using AHP method. This is computed at the initialisation of Controller block. This is a subjective method for the derivation of weights, we expect System Engineers to assess the criteria and provide pair-wise comparison. To make the overall technique sensitive to change in network, we use GRA method for overall ranking of alternatives. The unified list of weights from AHP method is provided to GRA to compute GRC for each contending Donor link and thus compute overall ranking. As per [18], for the case where nominal-the-best case does not exist, the $\Delta_{\max} = 1$ and $\Delta_{\min} = 0$. Hence, GRC for each Donor link is simplified as follows:

$$\text{GRC}_{\text{Donor link } i} = \frac{1}{\sum_{p=1}^6 (w_p |x_{\text{Donor link } i}(p) - 1| + 1)} \quad (14)$$

where $i = 1, 2, 3$, and 4.

In case of Entropy-RoV model, we first compute the weights of each criteria using entropy method using (8)–(10). Once the weights are available, we use (11)–(13) to compute the best, worst utilities and overall ranking of each alternatives.

Decision Making Phase: The selection of Donor link is performed in this phase. The Donor link with the highest rank is selected for offload.

3.2 Simulation

The simulation model with Beneficiary and multiple Donor links is as shown in Fig. 1b. In this section, we evaluate the Donor link selection parameters. In Table 2, we highlight the criteria that are fixed and those that vary, when offload traffic increases in the Donor link. The variable criteria are adapted during data normalisation stage for computing the weight or the overall rank.

We also define the MADM category along with the default network parameters of Donor links. These default network parameters are defined without the offload traffic.

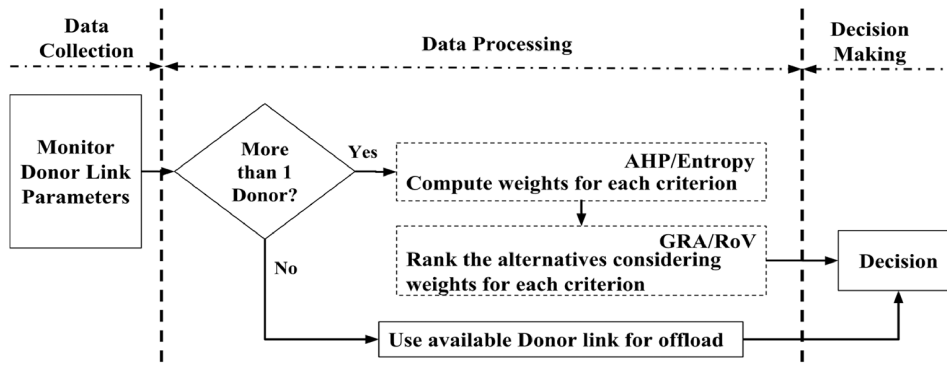


Fig. 3 MADM-based Donor link selection model for controller block

For the sake of convenience, the average Donor link throughput is set to 35 Mbps for all the links. The average traffic load (λ_D/μ_D) for the Donor link 3 is set to 0.25 (low load), and to 0.50 for other links. Donor link 2 prioritises its own traffic compared to the offload traffic. Hence the priority of offload traffic is set lower for Donor link 2 whereas for all other links we consider no priority between their own and offload traffic. The link utilisation (which is defined as $(\lambda_{\text{Offload}} + \lambda_D)/\mu_D$) is considered same as average traffic load (λ_D/μ_D) in the absence of λ_{Offload} . In terms of link usage cost, we consider Donor link 4 to be with very low usage cost (e.g. unlicensed spectrum), and Donor link 3 having higher normalised usage cost (value of 0.60) than Donor links 1&2 (value of 0.20).

For AHP, we perform pairwise comparison of each criteria and sub criteria as shown in Tables 3 and 4. Then, we derive the weights for each of them. The CR computed for pairwise comparison and is found to be <0.1. For unified weight vector, (6) is rewritten as,

$$\begin{aligned} \mathbf{W} &= \{w_\alpha w_d, w_\alpha w_z, w_\alpha w_h, w_\alpha w_q, w_b, w_g\} \\ &= \{0.0676, 0.2620, 0.0769, 0.2306, 0.1047, 0.2583\} \end{aligned} \quad (15)$$

The unified weights are listed in Table 5.

For GRA method, we derive the normalised parameter vector for each of the scenarios considering beneficial (larger-the-better) and non-beneficial (smaller-the-better) criteria. Here, we assign 1 to the upper bounds in beneficial situations and the lower bounds for non-beneficial situations. Other parameters are set to 0. The updated values are shown in Table 6.

For Entropy and RoV methods, there is no specific configuration done and the methods use the instantaneous data corresponding to each of the criterion for available Donor link for the computation.

From Tables 2 and 5, we infer that the main governing criteria for the Donor link selection using AHP-GRA technique are (a) lower average waiting time of λ_{Offload} (ζ), (b) higher relative priority of offload traffic (θ) in Donor link and (c) lower link usage

Table 2 Donor link default network parameters for MADM

Parameters	Criteria type	MADM category	Donor link 1	Donor link 2	Donor link 3	Donor link 4
QoS – average Donor link throughput, Mbps (δ)	fixed	beneficial	35	35	35	35
QoS – average waiting time of λ_{Offload} , ms (ζ)	variable	non-beneficial	0.22	0.22	0.12	0.22
QoS – average load in Donor link (η)	fixed	non-beneficial	0.50	0.50	0.25	0.50
QoS – relative priority of λ_{Offload} (θ)	fixed	beneficial	0.50	0.25	0.50	0.50
average link utilisation (β)	variable	non-beneficial	0.50	0.50	0.25	0.50
normalized link usage cost (γ)	fixed	non-beneficial	0.20	0.20	0.60	0.01

Table 3 Comparison of criteria for link selection

α	β	γ	Geometric mean (a)	Normalised global weight (c) = (a)/(b)	CR	
α	1	5	3	2.4662	0.6370	—
β	1/5	1	1/3	0.4055	0.1047	0.033
γ	1/3	3	1	1	0.2583	—
SUM (b)			3.8717	—	—	

Table 4 QoS sub-criteria comparison

δ	ζ	η	θ	Geometric mean (a)	Normalised global weight (c) = (a)/(b)	CR	
δ	1	1/5	1	1/3	0.508133	0.106181	—
ζ	5	1	3	1	1.96799	0.411238	0.012
η	1	1/3	1	1/3	0.57735	0.120645	—
θ	3	1	3	1	1.732051	0.361935	—
SUM (b)=				4.7855	—	—	

Table 5 Summary of weights of criteria for AHP

Criteria/sub-criteria	Weights
QoS – average Donor link throughput (δ)	0.0676
QoS – average waiting time of λ_{Offload} (ζ)	0.2620
QoS – average load (λ_D/μ_D) in Donor link (η)	0.0769
QoS – relative priority of λ_{Offload} (θ)	0.2306
average link utilisation (β)	0.1047
normalised link usage cost (γ)	0.2583

Table 6 Network parameters for each scenario for GRA method

Parameters	Scenario 1		Scenario 2		Scenario 3	
	Donor link 1	Donor link 2	Donor link 1	Donor link 4	Donor link 1	Donor link 3
QoS – average Donor link throughput (δ)	1	1	1	1	1	1
QoS – average waiting time of λ_{Offload} (ζ)	1	1	1	1	0	1
QoS – average load in Donor link (η)	1	1	1	1	0	1
QoS – relative priority of λ_{Offload} (θ)	1	0	1	1	1	1
average link utilisation (β)	1	1	1	1	0	1
normalised link usage cost (γ)	1	1	0	1	1	0

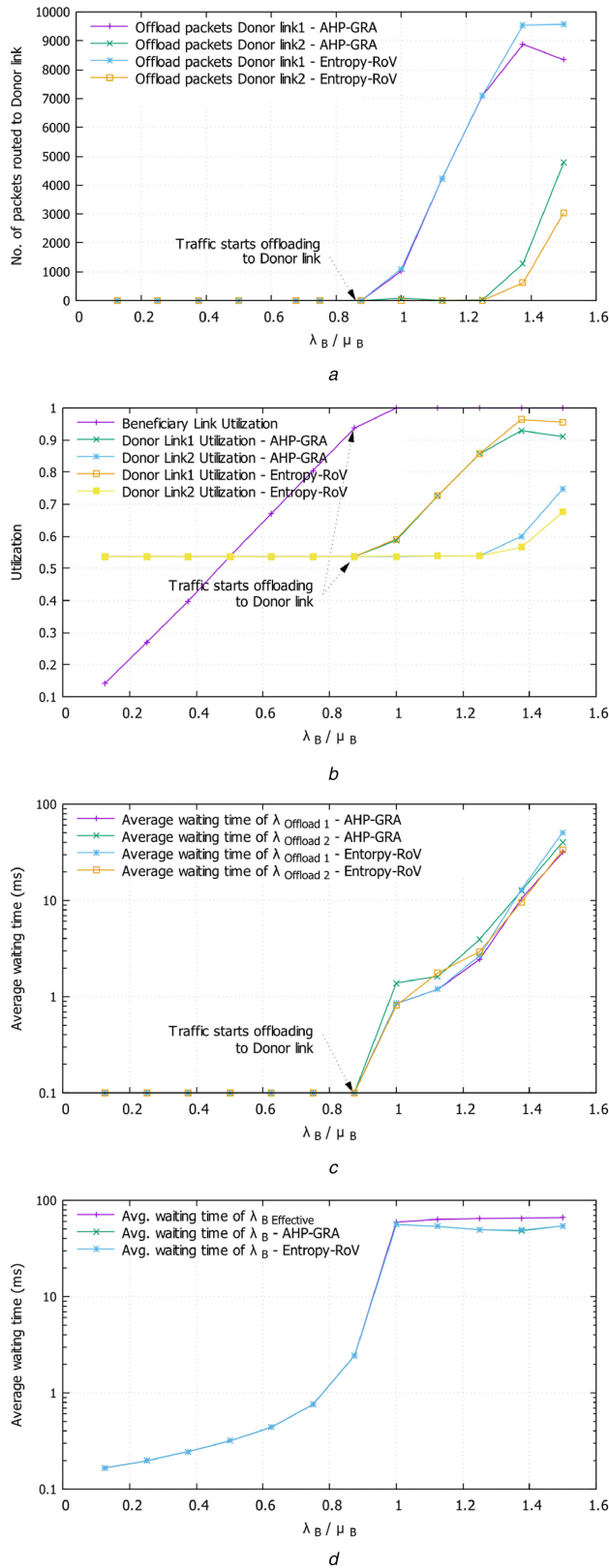


Fig. 4 Results for scenario 1,

(a) Volume of offload traffic routed to each Donor link, (b) Variation of link utilisation in beneficiary and Donor link, (c) Variation of average waiting time of $\lambda_{Offload}$ in Donor links, (d) Average waiting time of λ_B (benefits of traffic offload)

cost (γ). Hence, we create different scenarios by varying the values of these criteria to evaluate and compare the hybrid MADM based link selection. We limit the contending Donor links to at most two for each scenario.

We now define the scenarios in detail. In scenario 1, we select Donor link 1 and 2 for analysis. The default network parameters for both the links are similar except traffic handling priority. Donor

link 2 prioritises its own traffic more than offload traffic while Donor link 1 treats its own and offload traffic with the same priority. Both the Donor links have average traffic load (λ_D / μ_D) of 0.50. Hence this scenario evaluates the effect of increase of offload traffic on link selection when contending Donor links differ in traffic handling priority for offload traffic.

In scenario 2, we select Donor link 1 and 4 for analysis. The default network parameters for both the links are similar except the link usage cost. Both the Donor links have average traffic load (λ_D / μ_D) 0.50. But Donor link 4 has very less link usage cost. Hence this scenario evaluates the effect of increase of offload traffic on link selection when contending Donor links differ in just the link usage cost.

In scenario 3, we select Donor link 1 and 3 for analysis. Here Donor link 3 has lower average traffic load (λ_D / μ_D) of 0.25. Hence it has lower link utilisation and lower average waiting time for offload traffic. However the Donor link 3 has higher link usage cost compared to Donor link 1. Hence this scenario evaluates the effect of increase of offload traffic on link selection when contending Donor links differ in native traffic load and the link usage cost.

We now evaluate the performance of AHP-GRA and Entropy-RoV techniques through SimEvents simulation for all the three scenarios. In the simulation, we vary the Beneficiary ingress traffic to approximately 1.5 times the Beneficiary link load and check the following parameters:

- Volume of $\lambda_{Offload}$ to each of the Donor links
- Variation of Donor link utilisation
- Average waiting time for $\lambda_{Offload}$ in the Donor link ($W_{Donor}^{\lambda_{Offload}}$) and overall λ_B in both Beneficiary and Donor links ($W_{Overall}^{\lambda_B}$).

3.3 Results & inference

In this section, we provide results and inferences of the simulations, categorised for each scenario.

In Scenario 1, the Donor links 1 and 2 are the available links to service Beneficiary link's offload traffic. Both the Donor links have average load (λ_D / μ_D) of 0.50. Donor link 2 has traffic handling priority set to prioritising its own traffic over the offload traffic.

In Fig. 4a, we observe that once Beneficiary link traffic starts to offload, with increase in Beneficiary link ingress, most of the volume of $\lambda_{Offload}$ is routed to Donor link 1. This is also evident in Fig. 4b which captures the link utilisation. We see that for $\rho > 1$ in Beneficiary link, the Donor link 1 increases in utilisation whereas Donor link 2 stays flat.

In Fig. 4c, we observe higher average waiting time of $\lambda_{Offload}$ in the Donor link 2. This is expected since the $\lambda_{Offload}$ is prioritised lower than its own traffic in Donor link 2 and hence, increases the average waiting time. Donor link 1 is observed to have lower average waiting time and hence the preference to divert the $\lambda_{Offload}$ to this link. The trend is quite similar for both AHP-GRA and Entropy-RoV based techniques with subtle difference.

Fig. 4d, captures the benefit of traffic offload in scenario 1 and indicates that both AHP-GRA and Entropy-RoV-based techniques offer better link selection in terms of keeping the overall average waiting time of Beneficiary link low.

In Scenario 2, the Donor links 1 and 4 are the available links to service the offload traffic. Both the Donor links have average load (λ_D / μ_D) of 0.50. Donor link 4 has lower link usage cost compared to Donor link 1.

Fig. 5a captures the distribution of volume of the Beneficiary link offload traffic onto Donor links 1 and 4. Fig. 5b captures the variation of link utilisation and Fig. 5c captures the average waiting time of Beneficiary link traffic and the offload traffic in the Donor links.

We observe that once Beneficiary link traffic starts to offload, with increase in ingress, offload traffic is shared across both Donor link 1 and Donor link 4 (having lower link usage cost). In case of AHP-GRA technique, the IP packets were distributed in almost equal proportional to both Donor links 1 and 4, leading to load

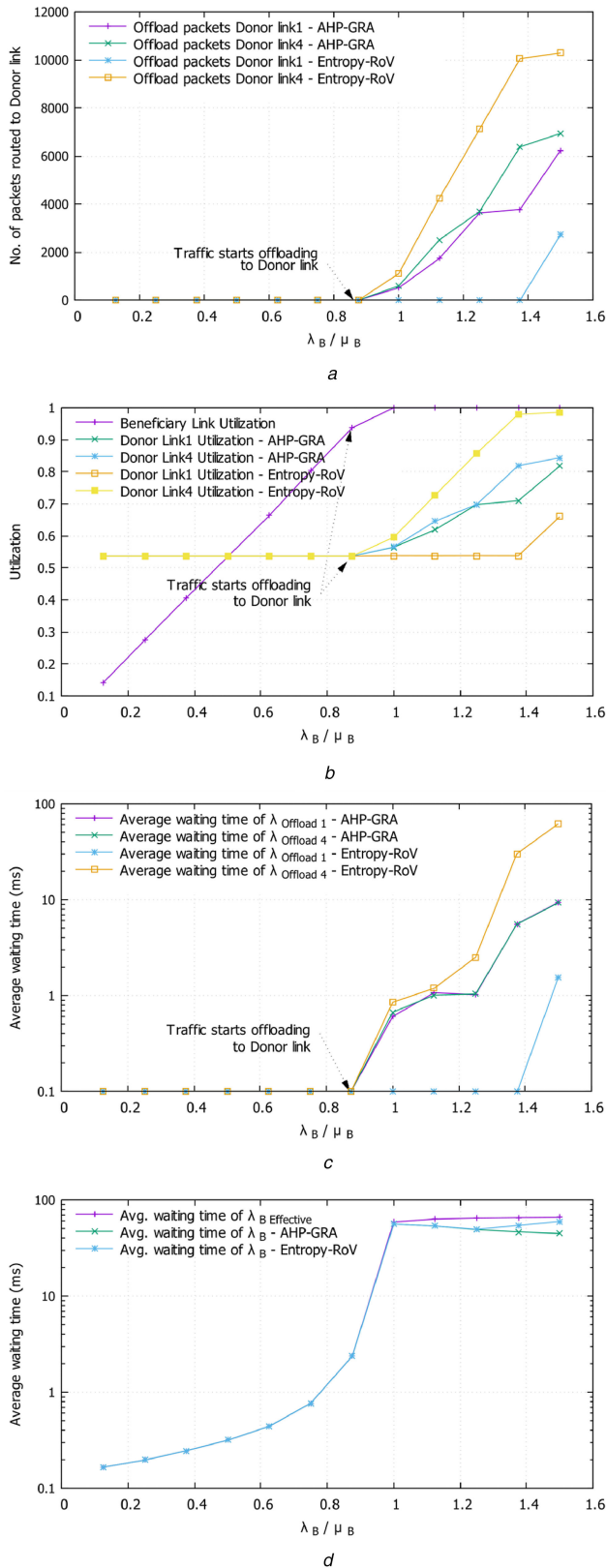


Fig. 5 Results for scenario 2,

(a) Volume of offload traffic routed to each Donor link, (b) Variation of link utilisation in beneficiary and Donor link, (c) Variation of average waiting time of $\lambda_{Offload}$ in Donor links, (d) Average waiting time of λ_B (benefits of traffic offload)

equalisation. For Entropy-RoV, IP packets are diverted to more to Donor link 4 since it has lower link usage cost compared to Donor link 1.

From Fig. 5c, we observe that in case of AHP-GRA, the average waiting time for $\lambda_{Offload}$ is quite similar for both the Donor links. From this trend, we infer that with the AHP-GRA technique,

the QoS criteria is taking precedence over link usage cost and this is as derived in Tables 3 and 4. For Entropy-RoV technique, since the volume of IP traffic is diverted mainly to Donor link 4, the average waiting time is higher. This is because, the weights computed using Entropy method is higher for link usage cost and, hence, is dominating factor in the selection of the link in this scenario.

Fig. 5d, captures the benefit of traffic offload in scenario 2. It indicates that both the AHP-GRA and Entropy-RoV techniques offer benefit by keeping the overall average waiting time of Beneficiary link low.

In Scenario 3, the Donor links 1 and 3 are the available links to service the Beneficiary link's offload traffic. The Donor link 1 had higher average load (λ_D / μ_D) but lower link usage cost compared to Donor link 3.

In Fig. 6a, for AHP-GRA technique, we observe that once Beneficiary link traffic starts to offload, with increase in Beneficiary link ingress, offload traffic is routed to Donor link 3 initially though it had higher usage cost. This is because, in Table 5, the QoS criterion is having more weightage compared to link usage cost as part of AHP computation. For Entropy-RoV technique, we observed that the IP packets are routed to link 1 (which was the link with lower usage cost) initially. We further observed rank reversal at certain point after which higher volume of IP packets are routed to Donor link 3.

Fig. 6b captures the variation of link utilisation and Fig. 6c captures the average waiting time of Beneficiary link traffic and the offload traffic in the Donor links.

For AHP-GRA technique, once the link utilisation and the average waiting time for $\lambda_{Offload}$ of the both the Donor links was comparable, the traffic volume is shared between Donor links such that load is equalised. This trend indicates that the QoS along with link utilisation criteria dominant over link usage cost in AHP-GRA technique. This can be inferred from Tables 3 and 4.

For Entropy-RoV method, the rank reversal did not impact the overall performance of this technique. We observe

Fig. 6d captures the benefit of traffic offload in scenario 3 and indicates that AHP-GRA scheme offers better link selection in terms of load equalisation and keeping the overall average waiting time of Beneficiary link low.

4 Conclusion

In this paper, we have developed a queuing model to represent a traffic offload situation with multiple Donor links. We found that traffic offload onto under-utilised links benefits the system, since it increases the utilisation of unused capacity in the Donor links. The IP packet scheduling priority in the Donor link plays a critical role in determining average waiting time of offload and Donor link's own traffic. The delay is governed by the Beneficiary link offload, the existing load in the Donor link and the packet scheduling priority between these two types of traffic.

We derived the criteria for selection of Donor links in a multi-MNO heterogeneous shared network and selected hybrid MADM techniques, namely, AHP-GRA and Entropy-RoV techniques for Donor link selection for traffic offload. We validated the hybrid MADM techniques through a set of scenarios using different combinations of traffic load, usage cost and IP packet scheduling priority in the contending Donor links. In all the scenarios, AHP-GRA as well as Entropy-RoV techniques offered benefits for overall Beneficiary link traffic with better average waiting time.

We observed that, for a given set of weights derived through AHP method, the QoS and link utilisation criteria were more dominant than the link usage cost for AHP-GRA technique. The AHP-GRA technique when configured suitably, performed as a load equalisation technique.

We further observed that Entropy-RoV technique aligned well with the dynamism of the network. The technique performed well in all three scenarios without any pre-configuration. We observed rank reversal when more than one criterion was varied (scenario 3), but it did not impact the overall performance of the technique.

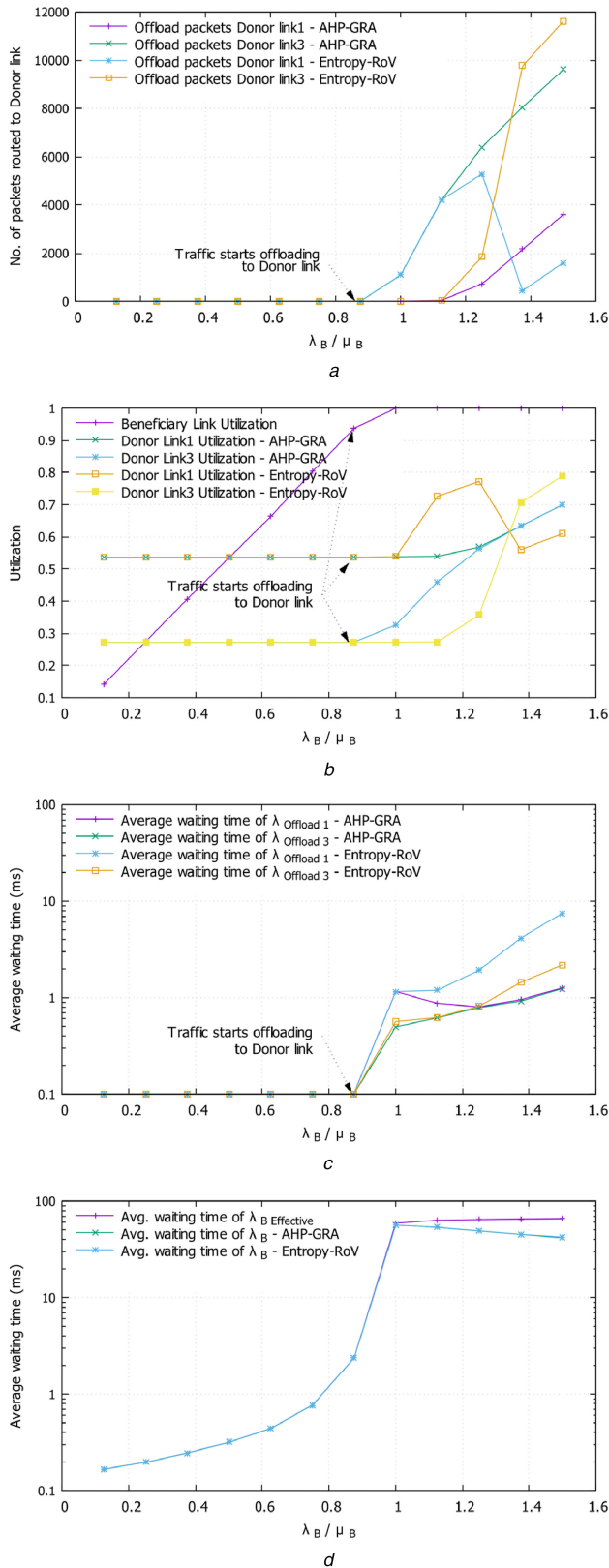


Fig. 6 Results for scenario 3, (a) Volume of offload traffic routed to each Donor link, (b) Variation of link utilisation in beneficiary and Donor link, (c) Variation of average waiting time of λ_{Offload} in Donor links, (d) Average waiting time of λ_B (benefits of traffic offload)

5 References

- [1] 'Cisco visual networking Index: global Mobile data traffic forecast update, 2016–2021'. Available at <http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.html>, accessed 29 May 2017
- [2] 'Nokia mobile broadband India traffic Index (MBIT index) 2018'. Available at <https://networks.nokia.com/in/mbit-index>, accessed 15 August 2018
- [3] 3GPP TR 36.889V13.0.0: 'Study on licensed-assisted access to unlicensed spectrum', 2015
- [4] MFA TS MF.202V1.0.1: 'Architecture for neutral host network access mode – stage 2', 2017
- [5] Irnich, T., Walke, B.H.: 'Capacity dimensioning to meet delay percentile requirements', in Takagi, H., Walke, B.H. (Eds.): 'Spectrum requirement planning in wireless communications: model and methodology for IMT-advanced' (John Wiley & Sons, Hoboken, NJ, USA., 2008), pp. 167–192
- [6] 'Cooperative association for internet data analysis, trace statistics for CAIDA'. Available at https://www.caida.org/data/passive/trace_stats/chicago-A/2016/equinix-chicago.dirA.20160317-130000.UTC.df.txt, accessed 29 May 2017
- [7] Holma, H., Toskala, A.: 'LTE for UMTS – OFDMA and SC-FDMA based radio access' (John Wiley & Sons Ltd., Hoboken, NJ, USA., 2009), pp. 241–242
- [8] 3GPP TR 32.425V14.1.0: 'Performance measurements evolved universal terrestrial radio access network (E-UTRAN)', 2016
- [9] Whaiduzzaman, M., Gani, A., Anuar, N.B., et al.: 'Cloud service selection using multicriteria decision analysis', *Scientific World J.*, 2014, **2014**, Article ID: 49375, pp. 1–10
- [10] Stevens-Navarro, E., Wong, V. W. S.: 'Comparison between vertical handoff decision algorithms for heterogeneous wireless networks'. IEEE 63rd Vehicular Technology Conf., Melbourne, Vic., 2006, pp. 947–951
- [11] Wang, L., Kuo, G. S.: 'Mathematical modeling for network selection in heterogeneous wireless networks – a tutorial', *IEEE Commun. Surv. Tutor.*, 2013, **15**, (1), pp. 271–292
- [12] Saaty, T.L.: 'How to make a decision: the analytic hierarchy process', *Interfaces. (Providence)*, 1994, **24**, (6), pp. 19–43
- [13] Deng, J.L.: 'Introduction to grey system theory', *J. Grey Syst.*, 1989, **1**, (1), pp. 1–24
- [14] Shannon, C. E.: 'A mathematical theory of communication', *ACM SIGMOBILE Mob. Comput. Commun. Rev.*, 2001, **5**, (1), pp. 3–55
- [15] Rao, R. V.: 'Decision making in the manufacturing environment: using graph theory and fuzzy multiple attribute decision making methods', *Springer Sci. Bus. Media*, (Springer, London, UK, 2007)
- [16] Yakowitz, D. S., Lane, L. J., Szidarovszky, F.: 'Multi-attribute decision making: dominance with respect to an importance order of the attributes', *Appl. Math. Comput.*, 1993, **54**, (2–3), pp. 167–181
- [17] Gustafsson, E., Jonsson, A.: 'Always best connected', *IEEE Wirel. Commun.*, 2003, **1**, (1), pp. 49–55
- [18] Song, Q., Jamalipour, A.: 'A network selection mechanism for next generation networks'. IEEE Int. Conf. on Communications, Seoul, South Korea, May 2005
- [19] Liu, Y., Zhou, X., Ren, S.: 'Peer selection in mobile P2P networks based on AHP and GRA'. 2012 18th IEEE Int. Conf. on Networks (ICON), Singapore, 2012
- [20] Dudnikova, A., Dini, P., Giupponi, L., et al.: 'Multi-criteria decision for small cell switch off in ultra-dense LTE networks'. 2015 13th Int. Conf. on Telecommunications, Graz, Austria, 2015, pp. 1–8
- [21] Fu, J., Wu, J., Zhang, J., et al.: 'A novel AHP and GRA based handover decision mechanism in heterogeneous wireless networks', In Zhu, R., Zhang, Y., Liu, B., et al. (Eds.): *Information Computing and Applications*. ICICA 2010. Lecture Notes in Computer Science, vol 6377, (Springer, Berlin, Heidelberg)
- [22] Khan, M., Han, K.: 'An optimized network selection and handover triggering scheme for heterogeneous self-organized wireless networks', *Math. Probl. Eng.*, 2014, **2014**, pp. 1–11
- [23] Lei, K., Wang, J., Yuan, J.: 'An entropy-based probabilistic forwarding strategy in named data networking'. IEEE Int. Conf. on Communications, London, UK, 2015, pp. 5665–5671
- [24] Hajkowicz, S., Higgins, A.: 'A comparison of multiple criteria analysis techniques for water resource management', *Eur. J. Oper. Res.*, 2008, **184**, (1), pp. 255–265
- [25] Madić, M., Radovanovic, M., Manić, M.: 'Application of the ROV method for the selection of cutting fluids', *Decis. Sci. Lett.*, 2016, **5**, (2), pp. 245–254
- [26] Isik, A. T., Adali, E. A.: 'The decision-making approach based on the combination of entropy and ROV methods for the apple selection problem', *Eur. J. Interdiscip. Stud.*, 2017, **8**, (1), pp. 80–86