Radio Resource Management in Multiple Virtual Networks

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Abstract: In future virtual networks environments, in which heterogeneous networks coexist and new business roles and models are expected, virtual networks cooperation for radio resource management is one of the most relevant issues, in order to achieve an efficient integration of different wireless technologies and the maintenance of QoS requirements. This paper proposes a set of mechanisms and strategies for Cooperative Virtual Networks Radio Resource Management in multiple and heterogeneous virtual network environments. A network model is presented in order to derive reference values for evaluation metrics. The obtained results show the great impact of wireless variability, e.g., the VNet Operator service level can range from zero to its maximum, from a “poor” to a “good” performance scenario. Hence, a fast reaction of the network in the reallocation of resources becomes a critical point for assuring a Virtual Networks proper deployment.

Keywords: Radio Resource Management, Virtual Networks, Heterogeneous Networks, Resource Allocation, Vertical Handover.

1. Introduction

Future Virtual Networks (VNets) [1] pose some new challenges in the scope of Cooperative Radio Resource Management (CooRRM) [2]. New stakeholders are expected in the market, like Infrastructure Providers (InP), VNet Providers (VNP), VNet Operators (VNO) and Service Providers. Since new relations and independencies must be considered, the interaction among these new stakeholders must be taken into account by CooRRM policies. Furthermore, the allocation of physical resources to different VNets introduces new constraints that should be considered to perform initial selection and handover decisions or radio resource allocation. At the Radio Resource Management (RRM) level, these constraints should also be taken in account, since the controlled radio resource unit pools are not static (from the operator view point). In fact, they are grouped according to the allocation of VNets, and may be reallocated to another VNet, or simply do not belong to any VNet.

The main aspects to be considered, in order to identify the various constraints added in this new framework, are the mobility of end-users and resources, VNets creation/migration dynamics, and the inherent allocation/reallocation of physical resources. Naturally, the nature of the wireless medium is one of the main constraints.

The network virtualisation concept is based on network infrastructure sharing by different VNOs. Thus, RRM in VNets could be seen as a problem of wireless network sharing for multi-operator networks, which is already studied for the introduction of Mobile
Virtual Networks Operators in 3G (Third Generation) systems. Several RRM strategies for 3G multi-operator networks have been proposed in the literature, since there is a critical need for radio resource control among the multiple operators [3], [4], [5]. However, a considerable difference exists, since in that case operators are forced to use similar network functions, as defined by 3G specifications; instead, in network virtualisation the existence of different types of functions and communication protocols for each VNet is a fundamental issue. On the other hand, the scope of those works is limited to one wireless access technology, and cannot benefit from possible trunking gains obtained by the cooperation among different Radio Access Technologies (RATs).

In this paper, CooRRM aspects in VNets, and its concepts are presented and discussed. Moreover, a network model to evaluate the VNet Requirements Radio Resource Control algorithm is proposed. This paper is structured as follows: CooRRM aspects in VNets are presented and discussed in Section 2; the network model is presented in Section 3, and some scenarios for evaluation are proposed in Section 4; results are presented in Section 5; finally, conclusions are drawn in Section 6.

2. Cooperative VNet RRM

According to VNets’ environment characteristics, two different levels of RRM functions should be considered, Intra-VNet and Inter-VNet ones. The former allows managing how end-users of a VNet share the resources of that particular VNet; it is the VNO that can freely define what kind of RRM it uses within its VNet. The latter, from now on designated as Cooperative VNet RRM (CVRRM), is responsible for managing how physical resources are allocated to different VNets. CVRRM ensures that every VNet gets the amount of resources as negotiated in the VNet establishment phase. It should be stressed that it does not operate on the resources that are required by an individual end-user; instead, it considers the aggregated resource demands of different VNets, nevertheless, it can be triggered by individual demands that affect the aggregated ones. In a multi-access analogy, CVRRM, and also Intra-VNet RRM, are equivalent to the Multi-RRM [6] or Common RRM [7], with the difference of the operational context.

The CVRRM set of functionalities is devoted to the characteristics abstraction of heterogeneous wireless environments, from the virtualisation process, keeping the main CooRRM target, i.e., to optimise network resources usage and to provide the always best connectivity, while ensuring VNets Quality-of-Service (QoS). The resources considered in the CVRRM context are the physical ones, nodes and links, and the virtual ones, Virtual Nodes (VNodes) and Virtual Links (VLinks). Radio resources, abstracted by channels, are also referred to in this scope.

CVRRM strategies should be based on a global knowledge of physical resources, their allocation to virtual networks, the resources neighbour mapping, and fundamental VNets characteristics to which resources are allocated. The VNet “owners” agreements (Inter-VNPs, Inter-InPs and VNOs) are also important information that should be known. Therefore, CVRRM can react not only to the changes in the amount of resources allocated to a VNet, but also to the end-user requests that affect the aggregated resources (VNodes/VLinks). Appropriate resources monitoring and evaluation can determine changes in the resource allocation in order to maintain or optimise VNet requirements. This evaluation is performed by a cost function that allows a unified comparison among all the resources, according to a given management policy, derived from [8].

Based on CooRRM concerns, namely, initial RAT access selection, vertical handover, and resources scheduling/allocation, three CVRRM main functions were identified:

- **VNet Requirements Radio Resource Control (VRRC)** – that manages physical resources allocation to different VNets, in order to ensure the amount of resources negotiated at the VNet establishment; it takes the possible changes in
capacity/availability of radio resources that affect VNet requirements into account, e.g., data rate, delay, jitter, packet loss, and error rates.

- Initial VNet selection – allowing transparency to end-users in the process of VNet attachment and optimising VNets utilisation.
- VNet Handover support – in order to guarantee the always best connectivity, even when the VNet coverage is impossible, therefore, allowing handover between different VNets.

These CVRRM functions are distributed among physical nodes and Brokers’ entities. In the physical nodes, the VRRC collects information from resource monitoring entities and the virtualisation manager, and interacts with the resource allocation control for reallocation requests. Brokers can be located above VNO level, in which initial VNet selection accesses to VNets information and end-users profile, in order to evaluate the best VNet to select. An interface to the VNP Management is also considered, since a vertical handover decision can trigger VNet adaptation or extension, assuring the best connectivity.

3. Network Model

3.1 General Assumptions

In order to establish a network model, some assumptions are taken: uniform coverage by all the wireless systems under analysis, and the inexistence of a specific requirement from the VNO related to the wireless technology in use. It is considered that VNOs do not care about the specific wireless technology being use, as long as the contractual requirements are ensured. Moreover, it is assumed that end-user nodes are mobile and multi-homed, i.e., capable of supporting different radio interfaces, so that it can connect to any available network.

Concerning the wireless access technologies involved, one considers Time Division/Frequency Division Multiple Access (TD/FDMA), Code Division Multiple Access (CDMA), Orthogonal Frequency Division Multiplexing (OFDM), and Orthogonal Frequency Division Multiple Access (OFDMA), as they cover most of the current wireless systems (GSM, UMTS, WiFi, and LTE), which from now on are considered as examples of such access technologies. Although, radio channel multiple access definition for each wireless technology is different, a level of abstraction is added, enabling a common approach to manage all radio resources. It is considered that each wireless link is generically composed of channels, which varies in number and capacity according to the wireless technology involved. However, the characteristics of each technology are taken into account, in order to emphasise the specific factors that influence channel capacity. The main feature considered here is the channel data rate.

VNets are classified according to their contractual requirements.

3.2 Strategies and algorithms

CVRRM functions must interact with a Monitoring Entity (ME) (e.g., the In-Network Management resource monitoring in the context of the 4WARD project [9]), which provides real time measurements, like available resources quantity and quality, neighbouring resources and failure detection. Furthermore, it is assumed that a ME instance exists in the physical node, providing global resource monitoring information, and in each virtual node, collecting its own monitoring information. The monitoring of the whole VNet is done through the association of several MEs instantiated in each of its VNodes, constituting an aggregated system. It is assumed that the ME, mainly the real time monitoring part, monitors the wireless medium and the node, therefore, providing the cost function inputs to computation, in order to allow the comparison among resources, and among VNets.
The strategies used in particular by VRRC are related to the contractual VNet requirements, and are reflected by key performance indicators weights in the cost function computation for resource evaluation.

The VRRC algorithm uses monitoring information, to compare the actual capacity with the contractual one, then, deciding on radio resources (re)allocation to a given VNet. The selection of additional radio resources is made in two steps:

- According to the radio resources availability into the same physical link. A VNet borrowing margin, similar to the one defined in [3], is associated to the VNet type and is adapted according to VNet usage. As an example, in a VNet with best effort requirements, channels may be transferred (borrowed) to perform the total amount of data rate required by a VNet with stringent requirements, if no other channels are available. The opposite is only possible if the VNet with stringent is running on low usage.

- Based on the cost of neighbour resources, which reflects the resources availability according to an implemented strategy.

The scanning time of this decision process is adapted dynamically depending on resources utilisation, variability of the radio interface, and VNets characteristics.

VRRC may also decide on the migration or adaptation of the amount of resources allocated to the VNets, in order to optimise radio resource usage, e.g., when the virtual resource runs on low usage over a long period of time.

3.3 Evaluation metrics

In order to evaluate the VRRC performance, a set of output parameters was identified as follows: VNO satisfaction level, out of contract ratio and VLink utilisation. They are key indicators that allow a proper validation of the proposed model, by accessing critical issues related with the virtualisation process, such as virtual links with QoS guarantees. It is worthwhile to note that VNOs are indirectly the “users” from VRRC viewpoint.

The VNO satisfaction level, $S_{VNO}$, represents the VNO requests to use the remaining capacity, according to the contract established with the VNP, and this capacity is not available:

$$S_{VNO} = 1 - \left( \frac{R_{in_{VL}} - R_{act_{VL}}}{R_{VL}} \right)$$

where $R_{in_{VL}}$ is the data rate offered to the VLink, and $R_{act_{VL}}$ is the actual VLink data rate.

This equation is only applied when the data rate offered to the VLink is above the actual, and below the minimum contracted; otherwise, the value of $S_{VNO}$ is zero.

$S_{VNO}$ accounts for the effective decrease in the amount of contracted resources perceived by the VNO. The analysis of this parameter should be made at VLink and VNet levels. Indirectly, it allows evaluating the network capability to react to radio/channel impairments that reduce the availability of the virtual resources. It can be used to monitor the virtual links, in order to detect contract violations.

The out of contract ratio is defined as the period of time, over the total sampling one, for which VNet contracted capacity is not available. It is a global metric, independent of the service level experienced by the VNO, since in low VNet usage, capacity reduction may not be perceived, due to enough remaining capacity to satisfy the VNO requests.

$$r_i^{nav} = \frac{R_{VL}^{min} - \left( N_{ch}^T - N_{ch}^o \right) R_{ch}^{max} + R_{in_{VL}}}{R_{VL}^{min}}$$

where $N_{ch}^T$ is the total number of channels, $R_{ch}^{max}$ is the maximum channel data rate in a cluster of resources, and $N_{ch}^o$ is the number of occupied channels in the cluster.
where $\hat{R}_{ch}$ is the actual channel data rate.

The out of contract ratio can be computed for a VLink and a VNet. The objective of this metric is the evaluation of network reaction to radio/channel impairments that reduces the availability of the virtual resources under VNet contracted requirements. The scanning time adaptation to fast or slow variability of the medium is another target to achieve.

VLink utilisation is defined as the ratio of the number of occupied channels over the total number of allocated channels:

$\eta_{VL} = \frac{N_{VL, o}}{N_{VL, c}}$  \hspace{1cm} (4)

where $N_{VL, o}$ is the number of VLink allocated channels.

This global metric should be applied to the individual VLinks in order to evaluate the possibility to introduce some balancing mechanisms to optimise physical link utilisation.

4. Scenarios for evaluation

In order to have reference values for each of the evaluation metrics, different scenarios were identified, being derived from a base one. The base scenario consists of a cluster of BSs, from the several RATs under analysis, deployed on a circular area. A uniform coverage by all RATs is considered, therefore, allowing vertical Handover in heterogeneous networks. Two VNets for data traffic are considered: Best Effort (BE), i.e., a VNet that has no data rate requirements, and Guaranteed (GRT), with stringent data rate requirements. Virtual resources instantiated in all the physical resources within the cluster, are assumed in both cases. Voice traffic is considered to be served by a dedicated VNet, which is not considered in this scenario. All physical resources are allocated for the two VNets, and it is assumed that the BE VNet gets twice the allocated data rate of the GRT one. The main reason for this is the typical data rate of the services provided by the BE VNet, which is higher than the one for the GRT VNet. Although other relationships could be considered, this one is used as an example.

Different cluster performances will be analysed to follow the data rate changes originated by adaptive modulation and coding schemes used by different RATs. Three performance cases are considered: Reference, Good and Poor ones. The Reference case corresponds to the mean data rate for each wireless technology, while in the Good one, the maximum data rate is considered. In the Poor case, the minimum data rate is obtained. The total cluster data rate, i.e., the capacity of the cluster to process the offered traffic, is calculated through the sum of the individual BS data rates for each RAT.

It is assumed that the maximum required data rate for the GRT VNet is the value reached in Good, and the minimum guaranteed data rate is the one obtained for Reference. The BE VNet has the minimum data rate requirement, i.e., the one obtained in the Poor. The number of end-users in the GRT VNet is twice the one in the BE VNet. As an example, one considers a cluster served by two GSM, five UMTS, eight WiFi and six LTE BSs.

For the base scenario characterisation, it is important to quantify the amount of offered traffic to the VNets, which is related to a typical data rate computed overall active end-users in the network during that period of time, hence, it is considered, from now on as the mean data rate per active end-user. A set of different services provided by each VNet is considered, according to their type. The GRT VNet runs services with stringent requirements, and the BE VNet provides other services, which do not have such stringent, Table 1. Tele-working/Interactive gaming has been included in the set of services, since it is expected to be of great impact in the future [10]. The offered data rate calculation per
active end-user was performed based on the mix of services presented on Table 1, using the mean value of the typical data rate interval. The obtained values for the offered data rate per active end-user in each VNet are 15.7 and 2.9 Mbit/s, for BE and GRT VNets, respectively.

Table 1: Service penetration per VNet (based on [10] and [11]).

<table>
<thead>
<tr>
<th>Services</th>
<th>Service penetration [%]</th>
<th>Typical data rate [Mbit/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BE VNet</td>
<td>GRT VNet</td>
</tr>
<tr>
<td>VoIP</td>
<td>57</td>
<td>[0.032, 0.064]</td>
</tr>
<tr>
<td>Video Streaming</td>
<td>28</td>
<td>5</td>
</tr>
<tr>
<td>Tele-working/Interactive gaming</td>
<td>15</td>
<td>[1, 20]</td>
</tr>
<tr>
<td>FTP</td>
<td>2</td>
<td>[1, 50]</td>
</tr>
<tr>
<td>P2P</td>
<td>56</td>
<td>[1, 50]</td>
</tr>
<tr>
<td>Web</td>
<td>29</td>
<td>[0.064, 2]</td>
</tr>
<tr>
<td>Chat</td>
<td>8</td>
<td>[0.064, 0.512]</td>
</tr>
<tr>
<td>Email</td>
<td>5</td>
<td>[0.064, 0.512]</td>
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</table>

5. Results

Results were derived by assuming static traffic values, therefore, allowing one to extract typical and bound values for each of the parameters under study. This was performed for different values of the cluster performance. Hence, a relative comparison to the ones that will be obtained after the introduction of CVRRM algorithms can be achieved.

In a first step, the $S_{VNO}$ behaviour related to the increase of offered traffic was studied, in order to determine the maximum number of active end-users that allows the maximum $S_{VNO}$ value, Figure 1. From a previous evaluation for the Reference performance case, one concludes that approximately until 150 active end-users, corresponding to 50% of maximum data rate allocated, BE VNO maintains its maximum value ($S_{VNO} = 1$). For the GRT VNet, this related value is about 400 active end-users, corresponding to 50% of maximum data rate allocated.

![Figure 1: $S_{VNO}$ for the different performance scenarios.](image)

In order to evaluate the impact of different performance scenarios, $S_{VNO}$ was obtained for 150 and 200 end-users in BE VNet, hence, for 300 and 400 end-users in GRT VNet, Figure 1. As one can observe, there is a great dependence of $S_{VNO}$ on the performance scenario, reflecting radio interface conditions. It can be seen that, for the same number of active end-users in the VNet, $S_{VNO}$ can vary from its maximum value in Good to zero in Poor. In the latter, the VNO is not using all the contracted capacity, still, it cannot allocate more capacity to its end-users due to a severe degradation on the radio interface.

Since this is a static analysis, based on the offered traffic to the VNets, one needs to consider a light traffic situation as a starting point, corresponding to a reduced number of active end-users, to estimate bounds for the out of contract ratio, $r_{VNO}^t$. Figure 2.
Figure 2 illustrates the $r_{\text{nav}}$ variation for 100 and 194 end-users offering traffic to the BE VNet (i.e., 200 and 388 end-users in the GRT VNet). Under a severe degradation of radio interface conditions, depicted by Poor, the percentage of time the contracted capacity is not available increases with the introduction of more end-users. The limit case in Reference without GRT VNet contract violation is illustrated in Figure 2(b). In Poor, the GRT VNet will run all the time out of contract. In this case, in order to guarantee the stringent requirements of this type of VNet, the introduction of some mechanisms to compensate for capacity reduction must be considered. Although the same phenomenon occurs for BE VNet when the number of end-users is near its limit (145 end-users), it is not so critical due to the elastic characteristics of the traffic in this type of VNet, and the possibility of being delayed.

The main difference between VLink utilisation, $\eta_{\text{VL}}$, and physical link utilisation theoretical reference values are the quantity of channels that belongs to each one. While the physical link corresponds to the cluster total number of channels, the virtual link has only a fraction of the physical link in terms of number of channels, Figure 3.

From Figure 3, one concludes that the utilisation of the VLink, $\eta_{\text{VL}}$, achieves its maximum, in the Reference scenario, for 150 and 400 active end-users in the BE and GRT VNets, respectively. It can be also observed that the utilisation ratio difference, between Poor and Good increases from 0.25 (25 active end-users in GRT VNet) to 0.75 (200 active end-users in GRT VNet) when the number of active end-users increases. When the number of end-users using the VNets is higher, the deterioration of the radio interface is more critical, since this reduction is perceived by all end-users.
6. Conclusions

This paper presents CVRRM concepts, and a network model to evaluate a proposed VNet Requirements Radio Resource Control algorithm.

Three CVRRM main functions were identified, namely, Requirements Radio Resource Control, initial VNet selection, and VNet Handover support. The first allow managing the physical resources allocation to different VNets, in order to ensure the amount of resources negotiated at the VNet establishment. The second allows for transparency to end-users in the process of VNet attachment, optimising VNets utilisation. The last one intends to guarantee always best connectivity, even when the VNet coverage is impossible or a best VNet is in the area, allowing for handover between VNets.

The network model is based on a cluster, with VNets composed by heterogeneous networks, and all RATs covering the area. Results suggest that the radio channel variability is a challenge for the deployment of virtual networks with guaranteed requirements, e.g., the VNO service level can rise from zero to its maximum, from a Poor to a Good performance scenario. Results from simulations will be extracted to analyse the proposed algorithm impact on a dynamic environment.

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