

Multi-Operator Resource Sharing Scenario in the Context of IMT-Advanced Systems

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Abstract— This paper investigates and proposes a framework for the efficient integration of functionalities for dynamic spectrum use (e.g., spectrum aggregation) and cooperative radio resource management (RRM) in the scope of IMT-Advanced (IMT-A) candidate systems. The envisaged technical solution is based on a joint centralized and distributed approach for both intra-and inter-operator scenarios. Spectrum assignment decisions benefit from a distributed approach that can be realized by the pooling of resources at higher layers together. The paper investigates the possible interworking between the two techniques for the benefits of achieving higher performance and capacity gains. Based on the proposed framework, operators will be able to demand portions of the spectrum for a certain time period and coordinate this action with the actual network loads. The framework is described in terms of functionalities, physical entities, and mutual interactions. The proposed integrated framework can reduce the CAPEX and OPEX during the deployment of IMT-A systems.

Keywords-component: dynamic spectrum use, radio resource management, centralized and decentralized approach, IMT-Advanced

I. INTRODUCTION

Mobile network operators are now preparing for the next generation of mobile communication systems. This is a transformation of cellular telephone networks into ubiquitous wireless broadband, which will be based on a new technology, called International Mobile Telecommunications Advanced (IMT-A) [1]. Affordable, high-bandwidth mobile access improves the quality of experience for users, enabling them to get more out of existing services, and opens up opportunities for new mobile broadband services. By delivering more capacity through faster radio access technologies (RATs), a universally accessible broadband infrastructure will improve the value of these services. The standardization of IMT-A technologies for preferred spectrum use in frequency bands announced by WRC-07 is, however, still a challenge to overcome [2]. The existing highly fragmented radio frequency spectrum does not match the actual demand for transmission and network resources, and there is a need for a revolution on how regulators manage spectrum. Mobile devices that implement various RAT standards (i.e., multiband devices) increase the complexity of coordination, reuse of resources and interference management. This research addresses spectrum and network sharing for IMT-A systems, and proposes an innovative way to coordinate and manage spectrum and

network resources in the context of user centric mobile broadband services. The proposed concept is for the integration of the spectrum and resource coordination into a single framework with the objective to enable improved performance and capacity gains. It has not been researched before in the context of IMT-A systems.

Decentralized spectrum and joint radio resource management were investigated in [3]-[5]. It was shown in [4] that competing UMTS operators can cooperate without operational information exchange and share a block of UMTS carriers simultaneously, to deploy multimedia services. An algorithm based on the total transmitted energy thresholds was proposed that could limit the loading by individual operators in the shared band and allow for coexistence. It was shown that dynamic spectrum sharing offers capacity gain due to the increase of the trunking efficiency in a spectrum-shared system. This improvement is achievable by the pooling of the radio channels belonging to different operators together. In [5], it was shown that proper underlying spectrum sharing coordination processes are required to manage the interference and to further increase the achievable capacity gains. The investigations were performed for UMTS and with the use of joint radio resource management (JRRM). JRRM is a distributed approach to resource management [4]. Besides, it was shown that the different proposed schemes have to be dynamically managed as a function of the traffic loads through the activation of the right strategies. This appropriate capacity management facilitates to get the best spectrum reuse opportunities. Finally, [3] extended the concept to a scenario of cognitive networks using a decentralized approach to both spectrum and RRM (i.e., JRRM). The proposed solution was based on a layered approach where spectrum sharing and JRRM were identified and integrated at both inter-and intra-operator levels.

This work goes beyond the previous work by exploring the possibilities of spectrum sharing integration (e.g., spectrum aggregation) and RRM functionalities in the context of IMT-Advanced systems. The concept supports cooperation between operators also when different RATs must share resources. The required functionalities and interactions are defined and an integrated framework is proposed. A combined centralized and distributed approach to RRM (i.e., cooperative RRM) that was proposed in [6] for inter and intra-system interworking is assumed. The spectrum management functionalities are

integrated with this framework. The rest of the paper is organized as follows. Section II identifies the challenges for the proposed approach in the context of IMT-Advanced systems. Section III describes the intra-operator sharing scenario and the types of achievable gains. Section IV describes the interworking between RRM and spectrum control entities in an inter-operator scenario. Section V concludes the paper and proposes further work.

II. COOPERATION FRAMEWORK FOR IMT-ADVANCED CANDIDATE SYSTEMS

The Wireless World Initiative New Radio project (WINNER) Phase I and Phase II [7] was a major EU-funded initiative joining the effort of major industrial and academic players in mobile communications. WINNER developed and designed an innovative high-performance system concept and validated it by performance assessments in realistic system deployments [7]. The WINNER concept is currently one of the candidates for IMT-A standardization together with other evolving technologies, such as Long Term Evolution Advanced (LTE-A [8]). The WINNER project considered spectrum management and sharing but did not investigate it together with use over fragmented frequency bands and network resource coordination. Spectrum aggregation was proposed for LTE-A, an IMT-Advanced candidate concept evolving from LTE. Although, LTE-A considers use of fragmented bands, it does not consider it together with network management strategies. This research uses the state of the art of the above system concepts and elevates them further by providing research results that are valuable to the definition of the deployment and user requirements of IMT-A systems and mobile broadband services.

Next generation communication systems are seen as being organized in a layered structure, comprising the following layers: distribution, cellular, hotspot, personal network and fixed (wired) ones [9]. These systems shall support the use of coverage enhancing technologies [9] as well. ITU-R M.1645 Recommendation [9] provided the initial requirements for the IMT-Advanced system concept. Legacy systems, such as GSM, UMTS, and WLAN, would continue to provide services to users; therefore, a generic framework for the support of the interworking between these, essentially, different systems is required. Interworking implies coexistence and sharing of resources. Coexistence means the concurrent operation of different radio systems in the same or in adjacent frequency bands without causing degradation to any other system, with emphasis on the indicated limitations in terms of, e.g., frequency separation, physical separation, and transmission resources. Sharing in the context of spectrum considers the use of a same frequency band by different radio systems, either with coordination or possibly without any coordination between the systems, with emphasis on the spectrum access schemes and methods. ‘Cooperation’ is the term used here to jointly refer to inter-working, coexistence and sharing.

The system concept developed in [7] proposed that cooperation (i.e., RRM) mechanisms for intra-system interworking are developed at the radio segment level of new RANs, following a combined centralized and distributed approach, while inter-system interworking is handled by a central entity located

outside of the RAN architecture following a centralized approach. A gateway (GW) functionality is an IP anchor to external data networks (e.g., Internet, corporate networks, operator controlled core networks) and operator services. It also terminates flows on the network side and serves as the anchor point for external routing. Thus, all functions that operate on user data traffic are located here [10]. Figure 1 shows the interworking of cooperative RRM and spectrum management functions at different levels of the radio access network architecture.

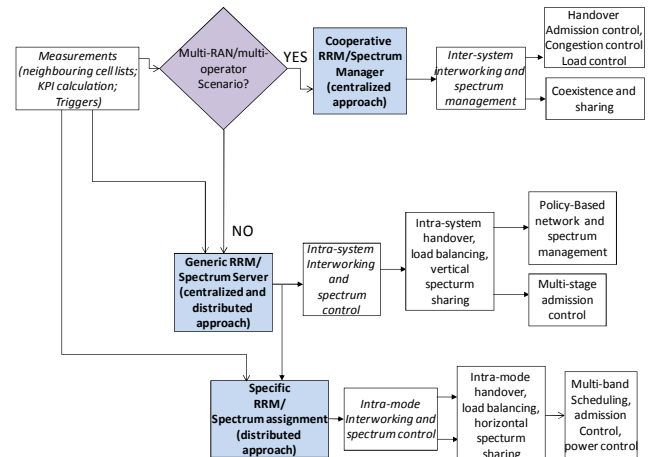


Figure 1. Cooperation framework for an IMT-Advanced candidate system.

The cooperative RRM and spectrum manager contain centralized RRM and spectrum sharing functions, and enable interworking, sharing and co-existence with other systems (RATs). These interface with the GW, which contains functionalities related to generic RRM and spectrum management on intra-system level in order to obtain information about the associated UTs and their characteristics. The generic RRM is in essence a centralized type of control but it allows a distributed approach, while the loads in the network are low-to-medium (i.e., specific RRM located at the level of BS or relay node (RN)). The spectrum server communicates spectrum sharing and spectrum assignment decisions to the BS. The spectrum server is accessible via the GW for spectrum negotiations. The BS containing the specific RRM functions is a point of radio access. The BS performs all radio related functions for active UTs (i.e., sending data) and is responsible for governing radio transmission to and reception from the UT in one cell. The interconnectivity of the functions in the support of the above framework is shown in the control and user plane from Figure 2. In practice, the amount of required spectrum bandwidth for a network operator will depend on the traffic / capacity requirements, the modulation scheme used, the cell sizes and the frequency reuse factor. The optimum balance is a commercial decision, based on these technical considerations.

A. Spectrum Aggregation Requirements

The concept of spectrum aggregation consists of exploiting multiple, small spectrum fragments simultaneously to deliver a wider band service (i.e., not otherwise achievable when using a single spectrum fragment). The best choice of a frequency band for a mobile communications system depends on many different factors [11]. In addition, once the spectrum has been obtained the problem of managing the shared band implies

proper user allocation mechanisms. Spectrum aggregation allows that new high data rate wireless communication systems can coexist while reusing the spectrum of legacy systems.

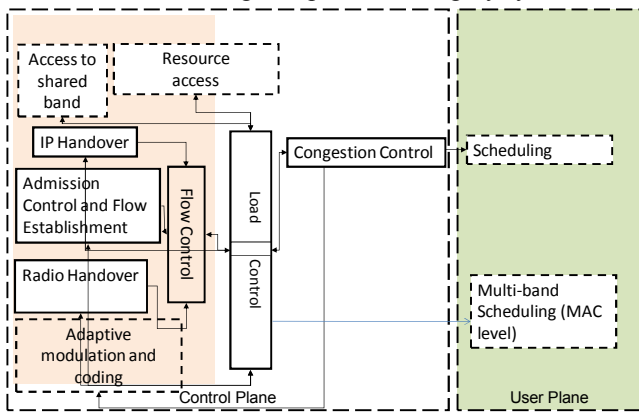


Figure 2. Interconnectivity of cooperative functions in the control and user planes.

In general, the lower frequency bands are better suited to longer range, higher mobility, lower capacity systems, while higher frequency bands are better suited to shorter range, lower mobility, and higher capacity systems. Therefore, for any given network the optimum frequency would vary depending on the required range, mobility and capacity [11]. For a commercial mobile network, the required range and capacity varies by changing the number of BSs (i.e. changing the size of their coverage area), so that the level of investment in the network infrastructure can affect the optimum balance. The White Paper of WWRF WG 8 [11] reported that spectrum for higher mobility applications (which are usually operating in interference limited scenarios) should be separated in the frequency domain from short-range applications (often noise limited scenarios), in order to avoid unnecessary complexity in sharing scenarios. This can be combined with a traffic split at higher RAN levels (i.e., GW level or generic RRM level) to explore the benefits of interworking at lower layers, while perceiving the network conditions and acting upon them.

Some factors, which should be taken into account to determine the best frequency band depend on the individual service requirements and the network requirements. These are explained here together with some considerations on how radio frequency bands should be managed once access to frequency spectrum has been obtained.

B. Research Hypotheses

The following research hypotheses for the system and the spectrum usage are made here:

- It is possible to reuse the existing infrastructure in terms of signaling, measurement, and protocol procedures with novel interference and resource management schemes;
- An integration of spectrum and network resource management functionalities can be exploited within an IMT-A scenario, while benefiting from higher performance and system capacity gains. The key to such integration is the pooling of the resources together; the integration allows for mapping of the

service requirements onto an available spectrum amount and translates the latter into network loads;

- It is possible to use the widely separated frequency bands for achieving lower delays and jitter and higher user throughput; this can be achieved by use of multi-band scheduling algorithms and exploiting the channel diversity;
- User allocation on various frequency bands can be performed based on the UT capabilities and performance gains in terms of increased peak data rate that can be obtained by use of specially designed algorithms for the management of the shared band;
- Information from the network about the system state (e.g., received signal strength, transmitted power, UT velocity, etc) and used in RRM procedures based on cooperative RRM [6], such as load, admission and congestion control can successfully be combined with dynamic spectrum use and reduce the need of spectrum aggregation in some cases; this will be achieved by the integration of functionalities for spectrum and RRM use and further optimized by the implementation of joint policies;

III. INTRA-OPERATOR CONSIDERATIONS

For simplicity, in the following discussions it is assumed that the UT is a single-band device. Spectrum aggregation can appear when an operator’s dedicated band is not continuous but is split in two or more parts. In addition, spectrum aggregation can happen in scenarios, in which an operator accesses both a dedicated band, and a spectrum sharing band which is separated in frequencies from the dedicated operator’s band. This is also valid for the inter-operator scenario. Once a portion of the spectrum has been obtained, it is important to identify the load on the network that the subsequent allocation in the bands will create. This requires that service requirements are translated into load values and in addition mapped to the available spectrum amount. A possible traffic split at generic RRM level (i.e., centralized control) can act upon the current load network conditions and assist the distributed approach to allocating users in the frequency bands without disturbing the balance of the overall network. The envisioned relationships between RRM and spectrum entities are shown in Figure 3. During spectrum aggregation, the amount of available spectrum resources in both shared band and dedicated bands will change.

A mechanism is required to match the available data in the queues to the available bandwidth. The scheduling of users over multiple frequency bands can be modeled in its most general form as a *General Multi-Band Scheduling* (GMBS) problem. A multi-band scheduler to manage the balance between the data pipe and the obtained extra source of spectrum was proposed in [12]. When the bandwidth from the shared band becomes available, the scheduler must be capable of realizing such a change in the spectrum pipe and shift some of the traffic load from the dedicated band to the shared band or vice versa. The scheduler must also be capable of further load balancing by actively monitoring the forthcoming changes

in the spectrum and traffic data in order to shift the load from the shared band to dedicated one and vice-versa, if so required.

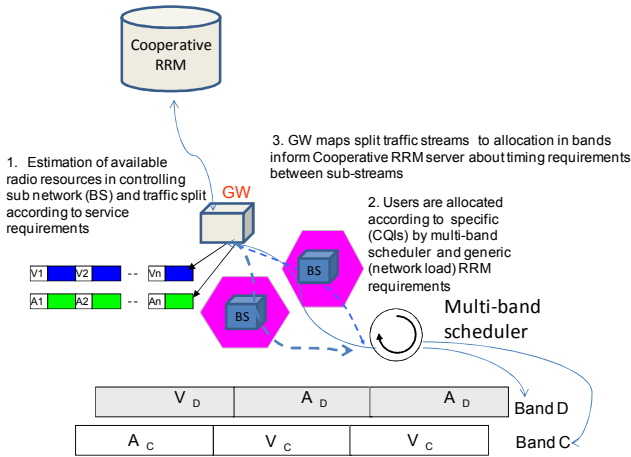


Figure 3. Translation of service requirements into network resources and mapping to spectrum availability.

Interworking between RRM and spectrum functions then can be translated into the objective of maximizing the total throughput of the operator, while considering the QoS requirements of the service classes. The more resources are available for a system, the higher the multiuser diversity gain that can be obtained [14], [15]. The performance is heavily dependent on the radio channel qualities for each user in the considered bands. The channel quality indicators (CQIs) depend on the path loss and on the distance from the BS. The operator will have good improvements when the UTs have heterogeneous spatial distribution in the cell (variable distances from the BS), i.e., different channel qualities in the considered bands. Here we can view the joint allocation on the dedicated and shared bands as cooperation at the scheduling level.

Figure 1 showed that at intra-system cooperation level a multi-stage admission control mechanism is active that uses the benefits of a joint distributed and centralized control for the admission of users to the network while balancing the load over a number of BSs and thus increasing the network throughput [13]. It was shown that through load balancing both gains from interworking at MAC level (i.e., multiplexing gain) as well as above the MAC (at generic RRM level) are realizable. It is proposed here to exploit this concept in relation to spectrum aggregation. The multi-band scheduling mechanism will be busy allocating users over the two frequency bands until the key performance indicators (KPIs) inform about a degradation of the QoS, which would mean that the allocation over the frequency bands does not match the current network (i.e., traffic) conditions. The operator then would rely on a generic or cooperative (i.e., centralized) RRM mechanism for restoring the network balance. Cooperative RRM would mean that the intra-system RRM has been exhausted and inter-system cooperation (still between systems belonging to the same operator) will be activated (i.e., cooperative RRM level). Such actions need to work concurrently with the scheduling over the available frequency bands. In this case, the achievable gain will be a combination of the gain from scheduling over separated frequency bands (i.e., diversity gain) and the trunking gain from resource

sharing (i.e., multiplexing gain achievable through traffic splitting and BSs interworking [13]). Future work will compare the achievable performance for each of the two gains.

IV. INTER-OPERATOR CONSIDERATIONS

An inter-operator spectrum sharing deployment scenario is one where each operator has access to a shared band, in addition to owning a dedicated band [16]. Two general spectrum-sharing deployments can be distinguished:

- Common frequency pool which is shared by all operators (considered here);
- Separated frequency pools, which are shared by two neighboring operators.

In the inter-operator case, the interworking can be seen as interworking at cooperative RRM level and allocation in the shared band. The two mechanisms for coping with the traffic demands can be seen as exchange of resources between operators at a system (i.e., cooperative RRM) and at a user level (i.e., sharing of the band). The multi-band scheduling mechanism can use the priority levels of the split traffic for assigning the traffic over the frequency bands and in case of changes in availability of the shared band, it can relocate traffic or decide to drop or reduce the bandwidth of less important flows. For this, an input from the sharing negotiation functionalities in the network is required. The exchange of resources at a system level is realized by using the logical functionality of the GW [10]. There are two types of GW logical nodes, the IP Anchor GW, and the control GW. The control GW provides control functions for UTs that are not active (i.e., not sending data) and functions that control and configure the IP Anchor GW. In practice, there would be several IP Anchor GWs as well as an independent number of control GWs. One BS can be connected to multiple GW logical pairs and conversely, one GW logical pair can be connected to multiple BS. Thus, the logical pairs of the GW form a pool of equipment that may cover large areas, e.g. cities. In [17] a hybrid handover was proposed based on the concept of using pools of GWs as a means to reduce the number of IP handovers (i.e., support of macro mobility). By using the logical association between the UT and GW independently of the BSs, the set of GW can be seen as a pool of resources. This in essence is a trunking gain realized by the sharing of resources between GWs and can be extended to the concept of GWs belonging to different operators. When degradation in the QoS is observed based on monitoring information from the KPIs, adding or removing of GWs can help bring the network in a balanced state (i.e., load balancing). This would reduce the observed delays due to signaling required for the user context transfer or the degradation of the QoS for some users, and even dropping of users due to the need to reallocate users in the shared band.

Without the use of the pool of GWs, when the shared band is unavailable a fast transfer to the dedicated band might be required to maintain the connectivity, and provide basic and priority services. In addition, there can be various reasons to initiate a frequency band transfer, for example the load in the other system with whom the resources are shared may change, a user terminal might move into an area where it would

interfere with the other system's transmissions, and so forth. Realizing the pool of GWs reduces the need for such actions because it allows for a centralized balancing of the load and resources, while preserving the logical associations of the UTs. Anticipation of a band reallocation improves the system performance because the contexts can be exchanged before the connection on the band is actually lost [12]. The information about this can be obtained by scanning other networks, or from the Cooperative RRM functionality that also implements a spectrum manager. The pooling concept is shown in Figure 4.

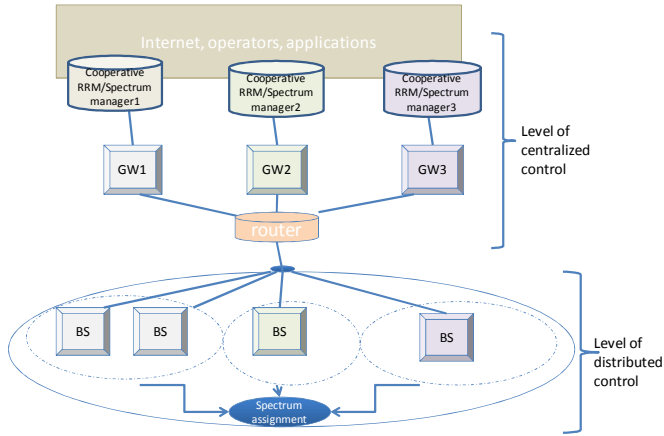


Figure 4. Pooling of resources of different operators.

Spectrum assignment is dictated on a short-term basis by the services used at the UT. As a result, it is a rather distributed method even though the information exchange between the different systems (belonging or not to different operators) can be distributed or centralized. The knowledge of the existing spectrum resources within a RAN may be centralized since this information belongs to each RAN, can be accessed through the spectrum server, and the available spectrum resources belong to a common pool between RANs. The spectrum information can be distributed to the BS, which in scenarios of low to medium loads, can take fast decisions and provide for multiplexing gain.

V. CONCLUSIONS

The system performance is affected by the subsystem capacities, the selection of an RRM algorithm, and the use of available radio resources. Both, single operator scenarios as multi-operator scenarios can benefit from a framework that supports a joint centralized and distributed approach to resource sharing. If the decision comes from the spectrum manager or spectrum server entities located higher in the network, the delays associated with the signaling will interfere with the timely assignment of resources during radio access. Therefore, the spectrum assignment should be performed as a distributed approach. Interworking between entities for network resource management and entities for spectrum management can provide a two-fold gain (i.e., trunking and diversity gain). The performance gain in terms of diversity would depend on the maximum acceptable distance between fragmented bands that are aggregated, in this context, it would be useful to investigate the upper limits on the separation and the achievable gain.

Currently, there is no reported information about how to cope with multiple bands and what are the added complexities both at the network managing and at the user terminal (UT) level, and to this end the paper provides a first insight into the possibilities of combining different RRM mechanisms designed separately for next generation systems. Future work will study the optimization problem for allocation of users on the shared band for single and multi-band UTs. Further, a comparison study will be performed to establish the achievable gains from resource sharing and interworking.

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