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RAN EVOLUTION PROJECT

MULTI-RAT JOINT RADIO OPERATION (MRJRO)

next generation mobile networks

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Abstract: This document presents the motives and business benefits of MRJRO, primarily centered around the dominance of multi-RAT deployment scenarios and the potential performance gains due to enhanced resource utilization with MRJRO. Based on MRJRO requirements, the hardware, reliability, adaptation and implementation requirements to introduce both semi-dynamic and fully dynamic MRJRO are specified. The constraints that stand in the way of MRJRO, mainly the introduction of Inter-RAT inter-cell Interference (IRI) and the management of control signaling in fully dynamic MRJRO, are also studied.

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1 EXECUTIVE SUMMARY

The continuous introduction of more efficient Radio Access Technologies (RATs) to meet the need for additional capacity has transformed single RAT cellular systems into multi-RAT systems. However, the static partitioning of system resources between co-deployed RATs, combined with the independent operation of different RATs, results in the suboptimal utilization of the limited system resources. Multi-RAT Joint Radio Operation (MRJRO) is proposed to improve the overall performance and resource utilization of multi-RAT systems.

This document presents the motives and business benefits of MRJRO, primarily centered around the dominance of multi-RAT deployment scenarios and the potential performance gains due to enhanced resource utilization with MRJRO. Based on MRJRO requirements, the hardware, reliability, adaptation and implementation requirements to introduce both semi-dynamic and fully dynamic MRJRO are specified. The constraints that stand in the way of MRJRO, mainly the introduction of Inter-RAT inter-cell Interference (IRI) and the management of control signalling in fully dynamic MRJRO, are also studied.

Two multi-RAT deployment scenarios, namely HSPA/LTE and GSM/LTE-A deployment scenarios, are considered. Different MRJRO solutions, with different architectural requirements to fit different deployment strategies of different operators, are specified for the considered MRJRO scenarios. Finally, recommendations on the evolution of multi-RAT systems to incorporate MRJRO are provided.

2 BACKGROUND

The exponential growth in mobile data traffic drives the development of more capable Radio Access Technologies (RATs), which take advantage of continuous technological advancements, to meet forecasted traffic demand and enable new services and applications. Introducing new RATs entails the modernization of both network infrastructure and User Equipment (UE). However, the time and costs required to upgrade network infrastructure and UE to support new RATs prolong the lifespan of legacy RATs as shown in figure 1. The wide spread of low cost UE that employ legacy RATs, in addition to applications that utilize legacy RATs such as Circuit Switch (CS) voice, international roaming and Machine-to-Machine (M2M) communications also increase the lifespan of legacy RATs. As a result, new RATs are co-deployed along with legacy RATs and the system resources are divided between co-deployed RATs. The partitioning of system resources is fixed, static and is applied at all system access points to ensure reliable operation of all employed RATs.

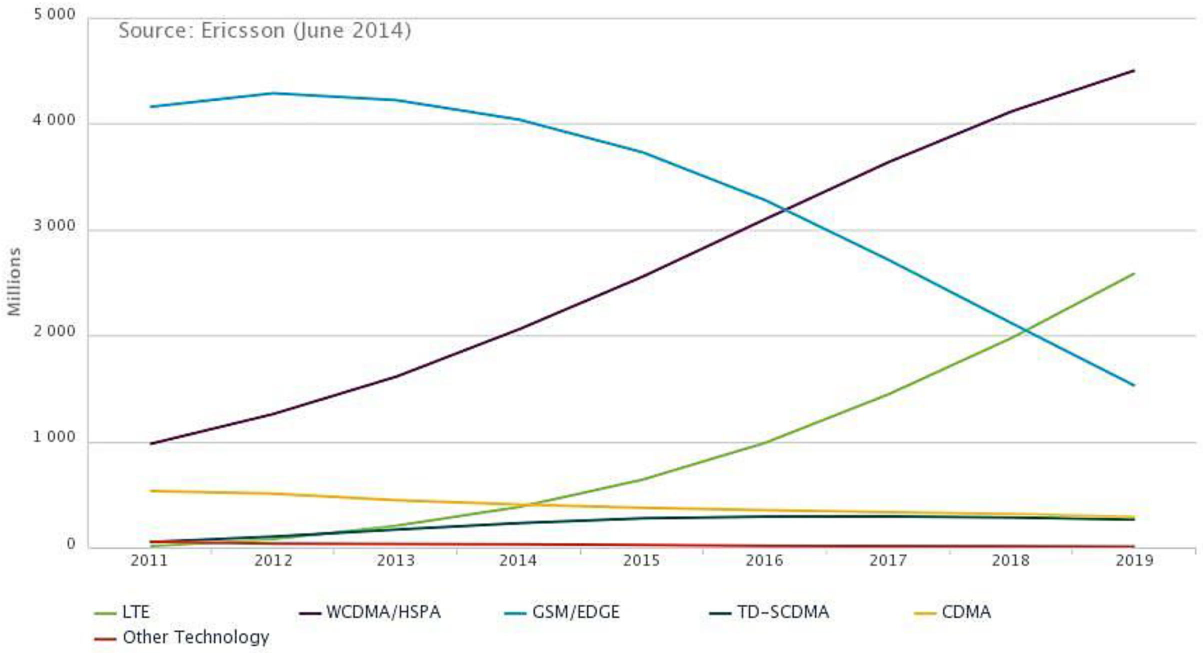

Figure 1:Global mobile subscriber base for different RATs [1].

Under fixed allocation, the amount of system resources allocated to any RAT must ensure that the system has the capacity to meet the peak traffic demand of all RATs at all times while maintaining the system Key Performance Indicators (KPIs). However, RAT-dependent traffic variations within cellular systems result in the suboptimal utilization of system resources for most of the time since system resources reserved to meet peak loading conditions are seldom used. Furthermore, system level allocation leads to geographically-unbalanced system loading, as shown in figure 2, as the system resources allocated to a specific RAT may be exhausted at certain locations while the resources allocated to other RATs are underutilized.

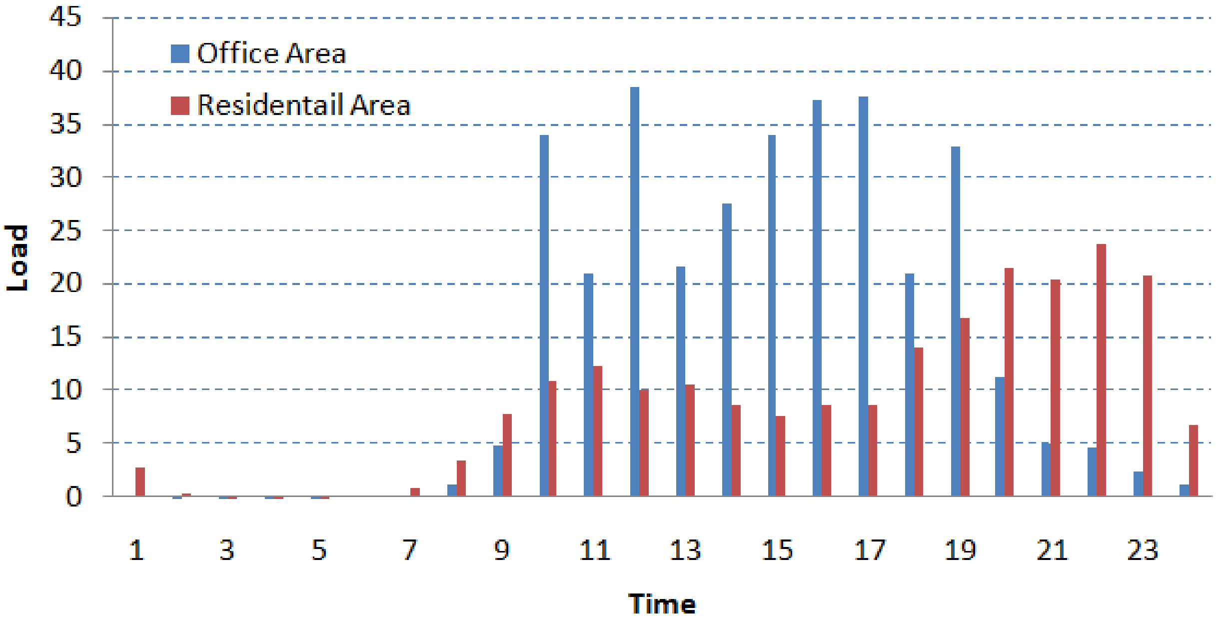

Figure 2: An example of daily traffic load at different locations [2].

In order to improve the utilization of system resources, resources allocated to legacy RATs experiencing declining traffic demand are removed from time to time, and reallocated at the system level (refarmed) to RATs with increasing demand as shown in figure 3. However, maintaining the capacity to meet Key Performance Indicators (KPIs) of all RATs at all times in all locations, particularly for applications with strict KPI requirements such as CS voice and delay-sensitive M2M applications, limits the amount of resources that can be deducted from legacy RATs. Due to the allocation of resources at the system level, having a small number of locations with high traffic demand for legacy RATs is sufficient to limit the amount of resources that can be deducted from legacy RATs. Furthermore, having varying busy hours at different locations limits the potential of adaptive system level refarming solutions such as the solution proposed in [3]. As a result, the resource utilization and performance gains achieved through refarming are limited and operators face the tradeoff of either having low utilization of system resources allocated to legacy RATs or compromising the performance and KPIs of legacy RATs. An alternative to improve the system load balancing and resource utilization is to move users between RATs and bands. However, such an approach suffers from two shortcomings. Firstly, the gains achieved are highly dependent on UE capabilities; as all UE are required to support all RATs and bands to realize the potential of such an approach. Secondly, user Quality of Service (QoS) and Quality of Experience (QoE) may be affected when moved to a lower performing legacy RAT.

The continuous need for additional capacity, combined with the suboptimal utilization of limited system resources, necessitate the need for resource allocation solutions that can adapt to traffic variations within cellular systems and fully utilize the available system resources. The purpose of this work stream is to pursue such solutions, henceforth referred to as Multi-RAT Joint Radio Operation (MRJRO).

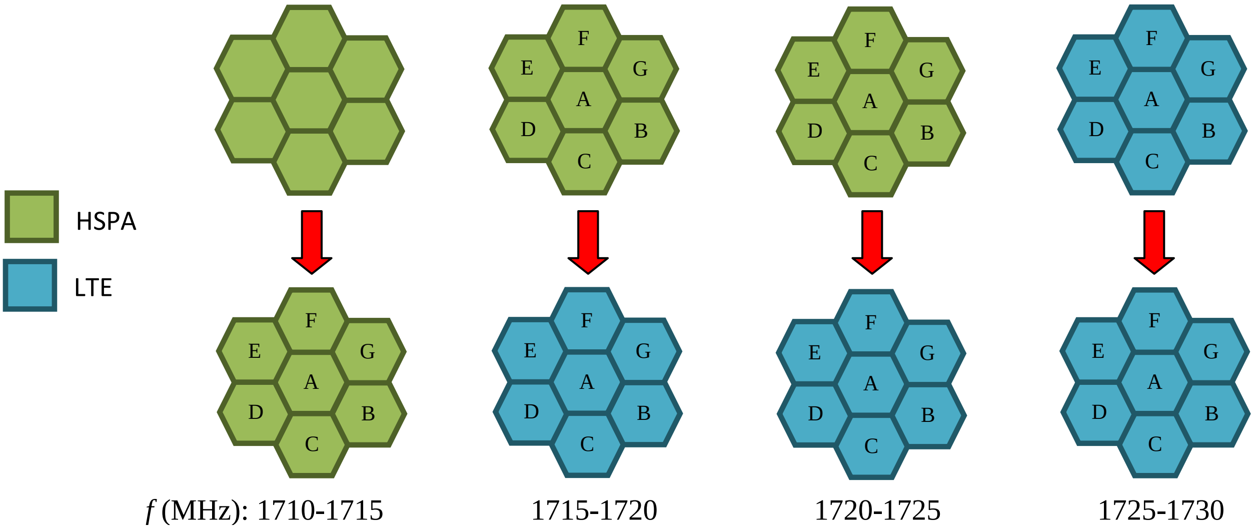

Figure 3: An example of refarming a 10 MHz block at a cluster of 7 cells.

3 MOTIVATION, OBJECTIVES AND GENERAL REQUIREMENTS

By maximizing the utilization of system resources, MRJRO is anticipated to reduce system congestions while improving the overall system performance and load balance. Furthermore, the seamless and adaptive reassignment of system resources assigned to legacy RATs enables supporting legacy RATs with minimal amount of required resources. High utilization of radio frequency resources is also a key factor in justifying the need for additional spectrum licensing and allocation.

Upon surveying the NGMN RANEV project members, the following results have been obtained:

- All members participating in the survey have multi-RAT deployment scenarios and see a need for some form of multi-RAT cooperation, particularly MRJRO.
- Almost 90% of surveyed members see a sufficiently long lived operation of legacy RATs, and are interested in having the flexibility to modify frequency resource allocation between RATs such that traffic variations are accounted for, possibly through the introduction of new interfaces and/or elements in legacy RAT architectures.
- Only 25% of the surveyed members are willing to invest in legacy RATs for reasons of enabling MRJRO alone.
- 75% of surveyed members support the 3GPP studying the impact of MRJRO.
- If centralized scheduling coordination is approved for LTE, 75% of surveyed members also support that LTE centralized scheduling coordination node should be enhanced to be a multi-RAT controller. If no LTE centralized scheduling coordination node is introduced, only about 40% of surveyed operators support the introduction of a standalone multi-RAT controller for MRJRO/multi-RAT cooperation.

The Findings of the project survey, in addition to the aforementioned business benefits of MRJRO, drove the development of this deliverable with the following objectives:

- Identifying MRJRO implementation requirements and constraints.
- Identify possible MRJRO scenarios.
- Provide different MRJRO solutions that fit the needs and business models of different operators.

With candidate MRJRO solutions being required to be capable of fulfilling the following requirements:

- Achieving optimal allocation of system radio resources at all locations in multi-RAT systems.
- Adapting radio resource allocation to traffic variations within multi-RAT systems.
- Maintaining the reliable operation of all employed RATs in multi-RAT systems.
- Having minimal impact on frequency planning, RAT structuring and system architecture.

4 MRJRO IMPLEMENTATION REQUIREMENTS AND CONSTRAINTS

Cellular systems are currently designed under the assumption of fixed allocation of resources at the system level and the independent operation of different RATs. As these design principles are altered to enable MRJRO, care must be taken ensure that service continuity is not disrupted and that the system performance is not compromised for all employed RATs. In addition, introducing MRJRO functions also requires interaction between RATs that entails architectural modifications to the system.

4.1 Inter-RAT Inter-Cell Interference (IRI)

Under fixed resource allocation, specific frequency bands are reserved for the exclusive operation of each RAT to ensure that interference is tightly controlled within the system and that different RATs do not interfere with each other [4]. The deployment of different RATs at different locations on the same frequency band introduces Inter-RAT inter-cell Interference (IRI) in the system. Given the variation in power spectral densities and the different transmission power levels of different RATs (as shown in table 1), the potential impact of IRI could severely limit the gains of MRJRO.

Table 1: Power transmission levels for different RATs.

Typical Base Station Transmission Power				UE Power Capabilities		
GSM TRx (200KHz)	HSPA carrier (5MHz)	LTE carrier (5 MHz)	LTE carrier (10 MHz)	GSM	HSPA	LTE
43 dBm	43 dBm	43 dBm	46 dBm	33 dBm	24 dBm	23 dBm

To address this issue, the effect of IRI under fixed resource allocation has been studied. The conclusions of the study [5] are as follows:

4.1.1 IRI Due to GSM

- Interference from GSM is found to significantly degrade the performance of both HSPA and LTE. The large IRI impact from GSM is mainly attributed to the higher power spectral density of GSM carriers in addition to the GSM carrier power leakage (as shown in figure 4).
- The processing gain of CDMA provides HSPA with better tolerance to IRI from GSM when compared to LTE.
- The choice of GSM frequency reuse factor (fr), in addition to the number of interfering GSM cells and carrier loading, play a vital role in determining the IRI impact due to GSM. HSPA and LTE are rendered incapable of operating on the same frequency band as GSM under worst-case IRI scenarios (all interfering cells use GSM, low fr with all carriers transmitting continuously). The IRI impact is less severe under more moderate interference scenarios (lower number of interfering GSM cells, higher fr and lower GSM carrier loading).
- IRI due to GSM has a higher impact on the uplink performance due to the significantly larger power capabilities of GSM UE when compared to HSPA and LTE UE.
- Cell edge performance is found to be more affected by IRI when compared to the average performance.

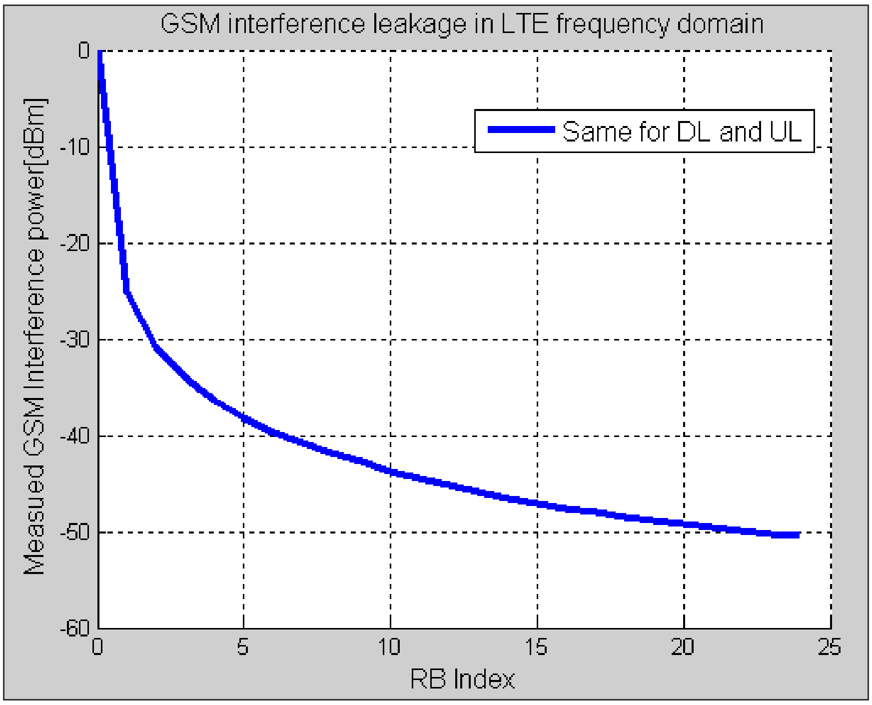

Figure 4: Carrier power leakage for GSM.

Note: In figure 4, a 0dBm GSM signal is imposed onto LTE #0 PRB as interference, the GSM signal leaks on the neighbouring LTE PRBs.

4.1.2 IRI between HSPA and LTE

- The impact of IRI between HSPA and LTE on the downlink performance is insignificant when compared to the case where no IRI is introduced and can be neglected.
- The impact of IRI between HSPA and LTE on the uplink performance is found to be tolerable and varies with the choice of power control mechanisms.

4.2 Service Continuity and Impact on User Mobility Management

Each employed RAT must have a dedicated carrier that is statically allocated at the system level to ensure service continuity and simplify user mobility management. MRJRO solutions that require moving users between carriers must ensure that user connectivity and QoE are not compromised.

4.3 Hardware Requirements

- Remote Radio Units (RRUs), Base Band Units (BBU), fronthaul and backhaul must support variable transmission bandwidths for each RAT and have the capacity to support the allocation of all pooled frequency resources to any RAT.
- MRJRO must be completely transparent to UE and must not affect the operation or performance of legacy UE.

4.4 Rate of Adaptation

The complexity and requirements of MRJRO solutions increase as the required adaptation rate, determined by the traffic variation rate between different RATs, increases. Only one RAT can be active on any frequency at any time in semi-dynamic solutions. Therefore, the limit on rate of adaptation in semi-dynamic solutions is set by the system hardware capabilities: The time required to change the transmission bandwidth, move users between carriers and switch carriers on/off. Fully dynamic MRJRO solutions, where radio frequency resources can be assigned to users on a frame/sub-frame basis, require the overlapping of different RAT carriers as detailed in the following section.

5 MRJRO SCENARIOS AND SOLUTIONS

Considered MRJRO scenarios are for Multi-RAT systems employing GSM and LTE-A (GSM/LTE-A) or HSPA and LTE/LTE-A (HSPA/LTE). Solutions with different levels of architectural impact and requirements are considered. With the exception of the uncoordinated GSM/LTE-A solution, all solutions introduce joint operation functions (either through coordination or joint allocation of resources) between RATs. The complexity of added functionalities varies with different solutions. MRJRO functions can be implemented either through defining an interface between RAT nodes or through the introduction of a common RAT controller that connects to all RATs as shown in figure 5.

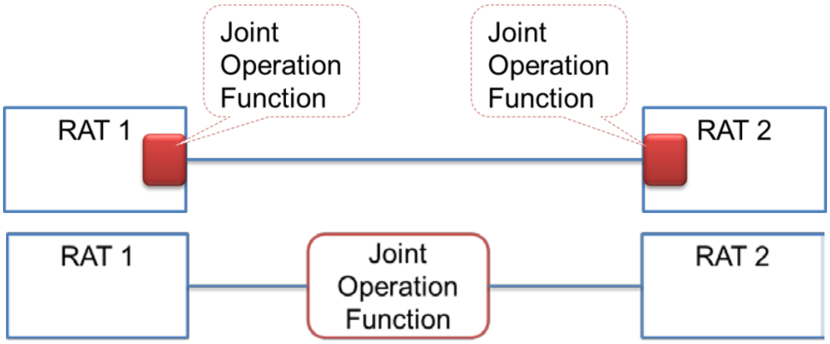

Figure 5: Possible implementations of MRJRO functions between two RATs.

GSM and HSPA have centralized controllers that are increasingly implemented on the same platform. LTE currently has a distributed architecture without a centralized controller and radio resource management is performed at the eNB. The lack of a centralized node in the LTE architecture would constrain the development of a single joint operation function that can coordinate multiple technologies as it would imply a substantial change to the LTE architecture is needed.

However, 3GPP has recently approved a new work item (RP-132103) for Inter eNB CoMP for LTE, supporting enhancement of network interface and signaling messages to allow implementing both centralized and distributed coordination. If a centralized coordinator for LTE in support of CoMP is widely used, this would facilitate the development of a Multi-RAT controller integrating the legacy BSC and RNC with this LTE coordinator and supporting MRJRO by also implementing joint operation functions.

5.1 HSPA/LTE Scenarios and Solutions

MRJRO solutions for the HSPA/LTE scenario take advantage of the low IRI impact between HSPA and LTE/LTE-A in addition to the commonalities between the radio interfaces of HSPA and LTE/LTE-A; such as supporting similar carrier bandwidths and frame durations. Both HSPA and LTE/LTE-A are required to have at least one dedicated fixed carrier to ensure service continuity as discussed in section 5.2. Semi-dynamic implementation of HSPA/LTE solutions divides pooled frequency bands into 5 MHz blocks, referred to as pooled blocks, that can be allocated to either HSPA or LTE/LTE-A as shown in figures 6 and 7, with LTE employing variable transmission bandwidth and LTE-A also having the option of aggregating 5 MHz carriers. Furthermore, pooled blocks can be independently allocated to either HSPA or LTE/LTE-A at each sector, as shown in figures 8 and 9, and the allocation of pooled blocks can be changed as necessary. Figure 10 illustrates the process of reassigning a pooled block in semi-dynamic implementation. The practical limit on the rate of adaptation for semi-dynamic implementation of HSPA/LTE solutions, as discussed in section 7.4, is set by the time required to move users between carriers and switch carriers on and off.

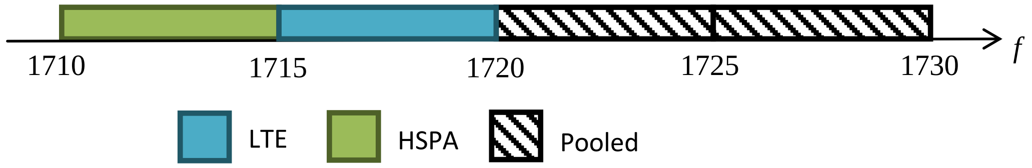

Figure 6: Single band partitioning example (20 MHz in band 4) for semi-dynamic implementation of HSPA/LTE solutions.

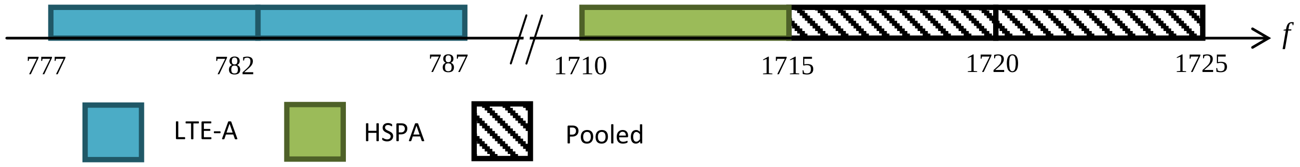

Figure 7: Dual band partitioning example (15 MHz in bands 4 and 10 MHz in band 13 with LTE-A carrier aggregation) for semi-dynamic implementation of HSPA/LTE solutions.

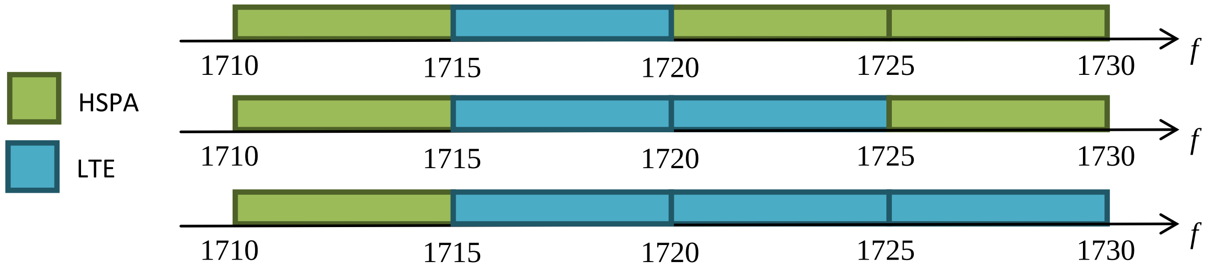

Figure 8: Possible frequency block assignment at individual cells for the partitioning of figure 6.

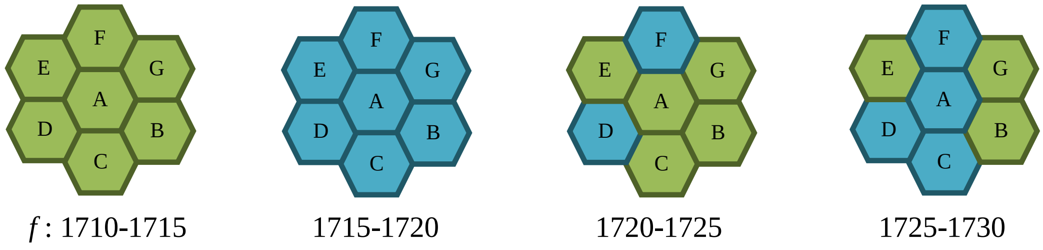

Figure 9: Examples of possible frequency block assignment at a cluster of cells for the partitioning of figure 6.

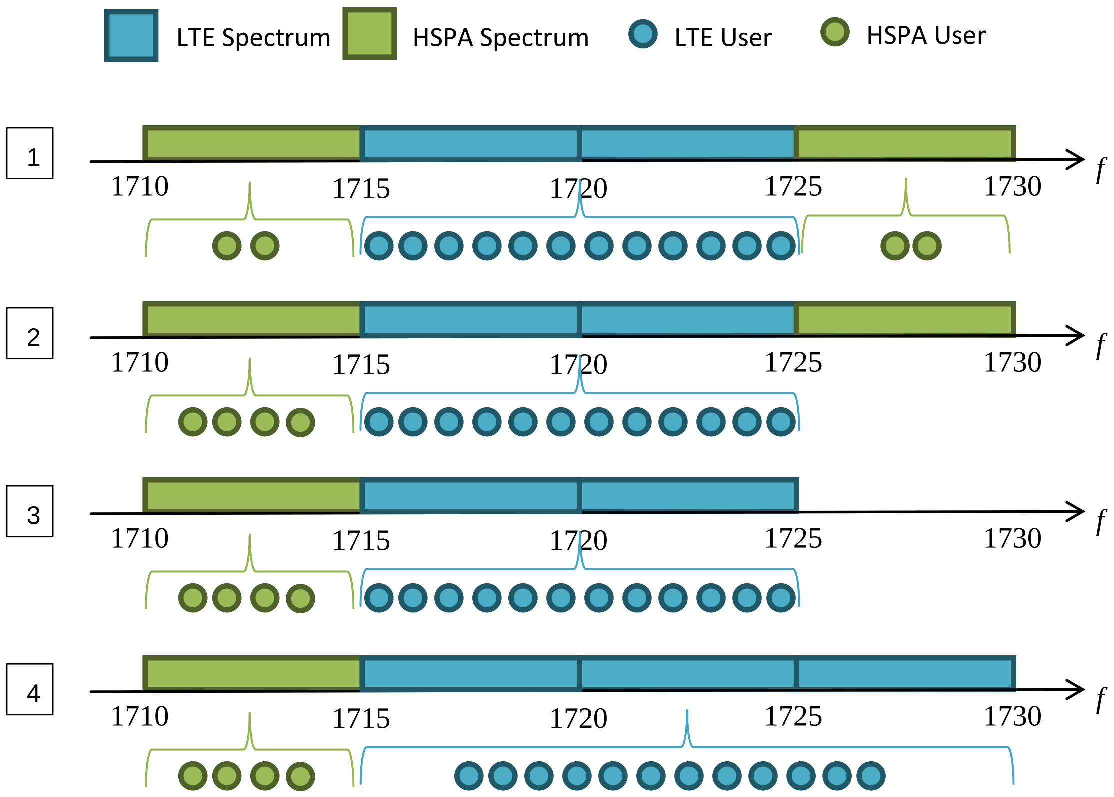

Figure 10: An example of reassigning a pooled block from HSPA to LTE in semi-dynamic implementation of HSPA/LTE solutions: 1- Initial allocation. 2- Moving HSPA users from pooled block to be reallocated to LTE. 3- Switching off the HSPA carrier on pooled block to be reallocated to LTE. 4- Assigning pooled block to LTE.

Fully dynamic implementation of HSPA/LTE solutions enables the rapid assignmemt/reassignment of user planes of both HSPA and LTE on pooled carriers. As in the semi-dynamic implementation of HSPA/LTE solutions, the general requirement of having a dedicated fixed carrier for both HSPA and LTE holds. UE are camped on dedicated carriers and HSPA and LTE carriers overlap in pooled blocks (as shown in figure 11). However, the user plane of only one RAT is active at any time as shown in figure 12 and UE can be scheduled on a pooled block only when it is allocated to their RAT. The signalling of resources on the HSPA HS-SCCH (shown in figure 11) in pooled blocks may occur at all times, as long as interference with the LTE signal is tightly controlled, or only during timeslots in which pooled blocks are allocated to HSPA. LTE PDCCH (also shown in figure 11) is transmitted on pooled blocks during timeslots in which pooled blocks are allocated to LTE while LTE-A performs cross carrier scheduling using the PDCCH of the dedicated LTE-A carrier.

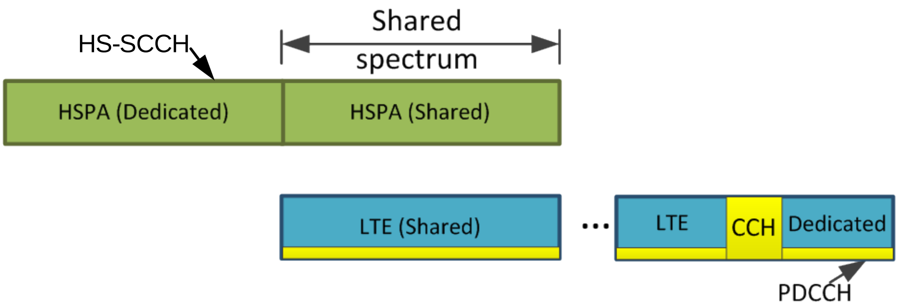

Figure 11: Spectrum assignment in fully dynamic HSPA/LTE solutions.

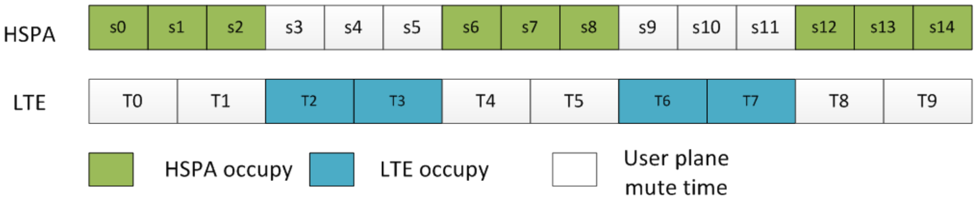

Figure 12: An example of user plane activity in time in fully dynamic HSPA/LTE solutions.

The MRJRO solutions for the HSPA/LTE scenario are shown in figure 13, with implementation requirements and deployment scenarios specified in table 2.

Table 2: Requirements and implementation scenarios for H/L MRJRO solutions

Solution	Architectural impact	Architectural Requirements	Rate of Adaptation	Implementation scenario
Coordinated	Low	• Interface between HSPA RNC and LTE eNB	Semi-dynamic or fully dynamic	Fast phase out of HSPA/ focus on LTE
Joint pooled Block Assignment	Moderate	• Pooled block assignment function	Semi-dynamic or fully dynamic	Medium to long term phase out of HSPA
Joint Scheduling/ Resource Allocation	High	• Unifying scheduling/resource allocation	Fully dynamic only	Continuous support of both HSPA and LTE

5.1.1 Coordinated HSPA/LTE Solution

HSPA resource allocation minimizes the number of employed HSPA carriers (rather than spreading users over available carriers) and unused HSPA carriers are switched off. Based on the HSPA carrier activity information that is provided to LTE, LTE accesses unused HSPA carriers (pooled blocks). By limiting the interaction between HSPA and LTE to HSPA providing LTE with carrier occupancy information, the architectural impact on HSPA is minimized. However, HSPA accesses additional carriers (pooled blocks) only when necessary even if pooled blocks are not utilized by LTE.

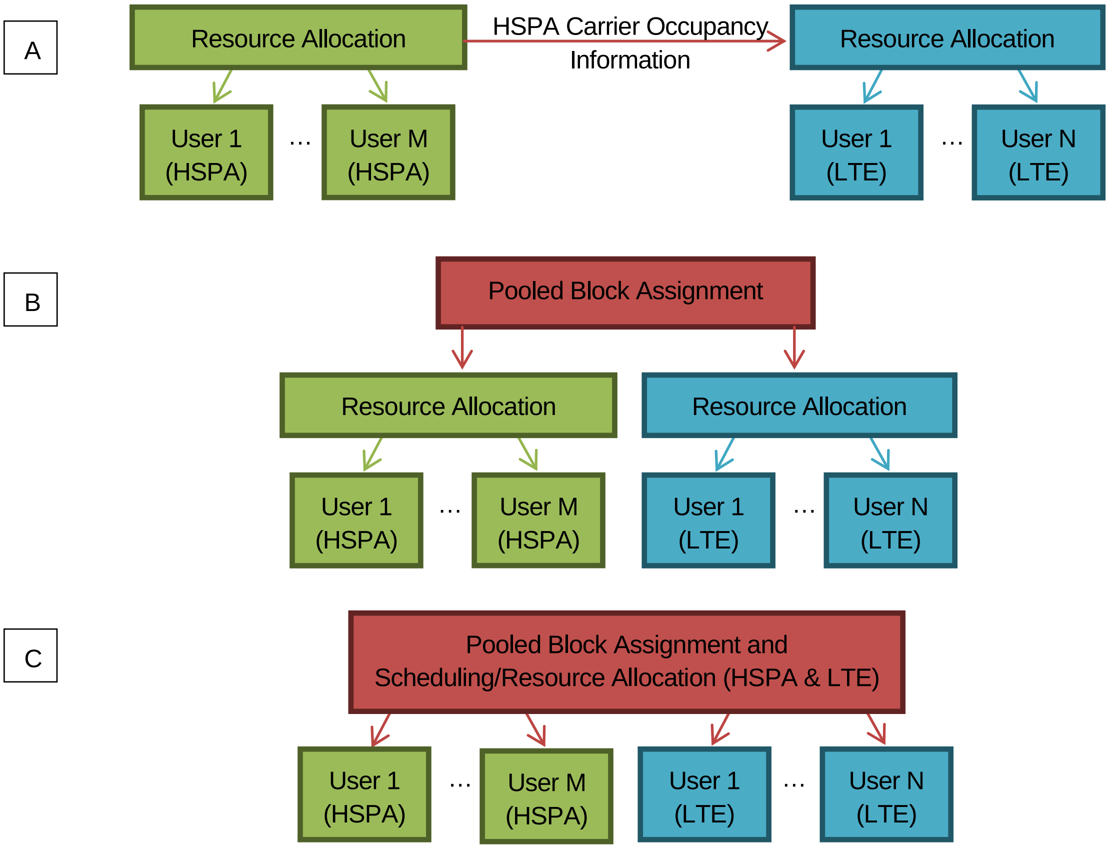

Figure 13: Resource allocation in the HSPA/LTE solutions: A) Coordinated solution. B) Joint pooled block assignment solution. C) Joint scheduling/resource allocation solution.

5.1.2 Joint Pooled Block Assignment Solution

A joint function that assigns pooled blocks (either to HSPA or LTE) at each cell is introduced. Allocation of pooled blocks at each cell is based on the cell loading of both HSPA and LTE. Each RAT independently performs scheduling/resource allocation based on the number of pooled blocks allocated to it as shown in figure 13. Having similar frame length duration for both HSPA and LTE enables the allocation of pooled blocks to either HSPA or LTE for as short as the frame length duration in fully dynamic solutions without disrupting the operation of both HSPA and LTE.

While this solution has a higher architectural impact than the coordinated solution (due to the introduction of the joint pooled block assignment function), it provides better flexibility in the allocation of pooled resources and enables achieving better overall performance when compared to the coordinated solution [6].

5.1.3 Joint Scheduling/Resource Allocation Solution

Unlike the joint pooled block assignment solutions, where each RAT performs resource allocation based on the pooled block assignment (i.e. resource allocation is divided into two stages performed by separate functions), a single entity directly assigns pooled blocks to HSPA/LTE users in the joint scheduling/resource allocation solution as figure 13 shows. Therefore, the joint scheduling/resource allocation solution is a fully dynamic solution. Jointly scheduling HSPA and LTE enables achieving the highest overall performance gains and optimal utilization of system resources at the expense of having the largest architectural impact due to the consolidation of HSPA and LTE resource allocation [7].

5.2 GSM/LTE-A Scenario

Unlike the HSPA/LTE scenario, the GSM/LTE-A scenario is affected by the significant IRI impact from GSM, the significant power leakage from GSM carriers and the lack of commonalities in the radio interfaces of GSM and LTE. Therefore, this scenario is applied between GSM and LTE-A with CA only; as the reliable operation of LTE cannot be guaranteed when deployed only on a band shared with GSM. Furthermore, the use of a GSM carrier in one sector can impact the operation of LTE in surrounding cells, and so, in contrast to the HSPA/LTE scenario some form of multi-site joint resource allocation may be needed. The GSM/LTE-A solutions are shown in figure 14 and are as follows:

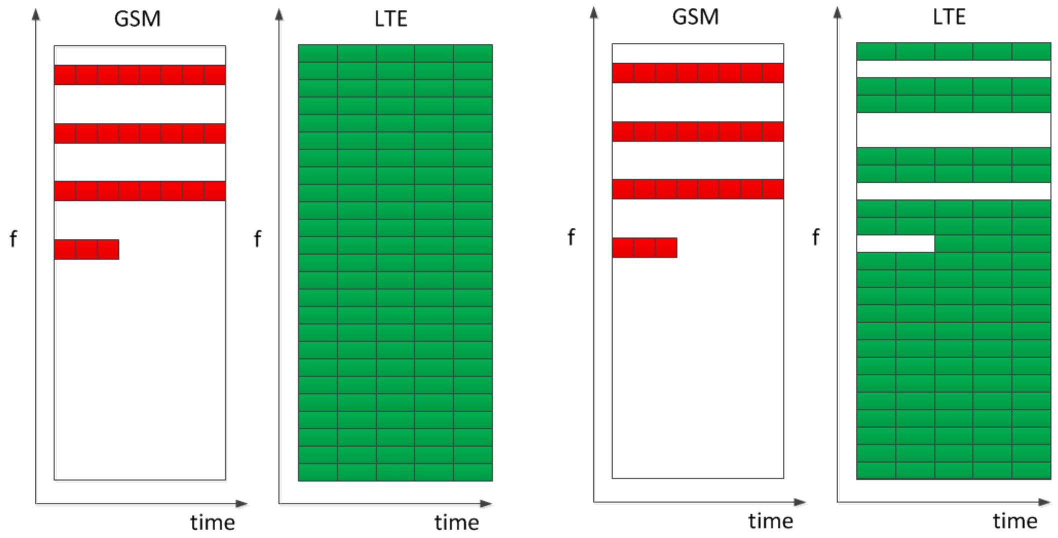

Figure 14: An example of resource allocation in coordinated (right) and non-coordinated (left) solutions for the GSM/LTE-A scenario (Note: only shared band is shown for LTE-A).

5.2.1 Non-Coordinated (Underlay) GSM/LTE-A Solution

As figure 14 shows, LTE-A CA secondary carrier is deployed on the same frequency band as GSM. In order to reduce the IRI impact on LTE-A, GSM resource allocation is modified to minimize the number of active GSM carriers (as in the HSPA/LTE coordinated solution) as shown in figure 15. The effect of GSM carrier leakage in the uplink can be reduced through using an enhanced base station receiver as shown in figure 16. While the non-coordinated GSM/LTE-A solution has minimal architectural requirements for both GSM and LTE-A, the large IRI impact reduces the benefit of employing such a solution in systems with larger fr and GSM loading.

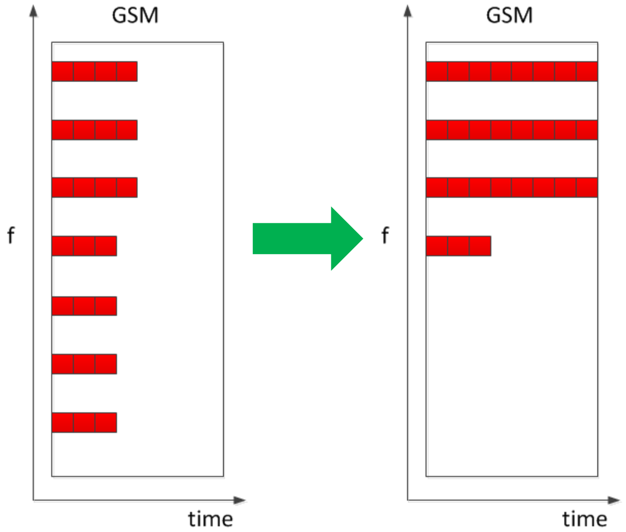

Figure 15: An example of altering GSM scheduling to reduce the number of active carriers.

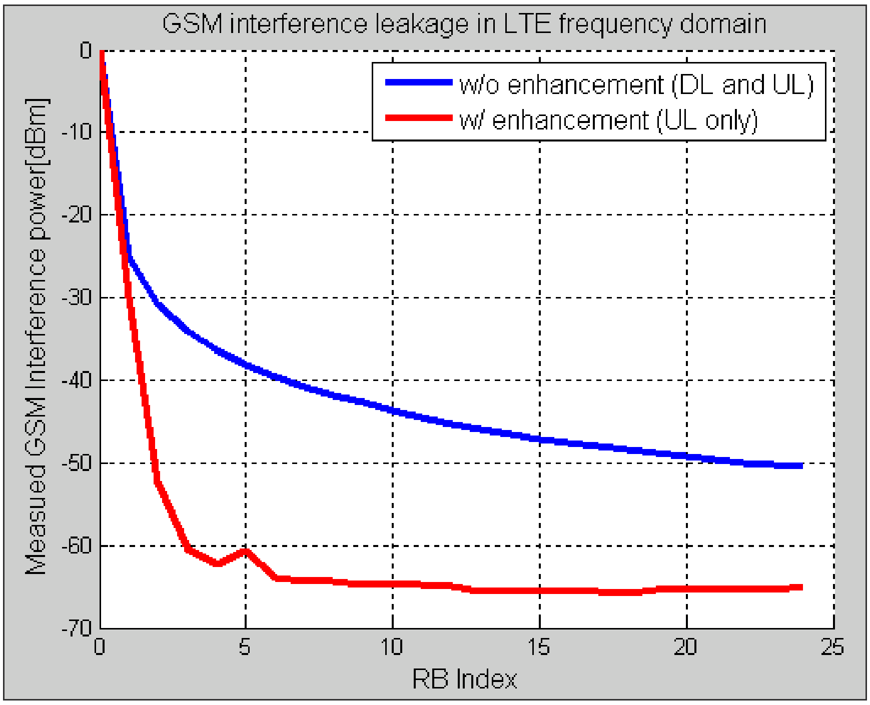

Figure 16: Carrier power leakage for GSM with enhanced base station receiver.

5.2.2 Coordinated GSM/LTE Solution

In addition to modifying the GSM resource allocation and employing an enhanced base station receiver as in the non-coordinated GSM/LTE-A solution, the coordinated GSM/LTE-A solution introduces an interface between the GSM BSC/multi-RAT controller and the LTE eNB to avoid assigning PRBs that overlap with active GSM carriers in both overlaying and neighboring cells, making it a fully dynamic solution. As shown in figure 17, the GSM BCCH is placed on a dedicated GSM carrier and the control signaling for the LTE CA secondary carrier is carried on PDCCH and PUCCH of the primary carrier located on the LTE-A dedicated carrier. Consequently, transmission of PCFICH on the LTE-A CA secondary carrier is not necessary. Avoiding interference between GSM TCH and common channels of the LTE-A secondary carrier (including PSS, SSS, PHICH and PBCH) is achieved through configuring GSM not to use the central 1.08MHz of the shared spectrum or, alternatively, through configuring LTE-A UE to not rely on the common channels of the secondary carrier; as PSS and SSS of the CA secondary carrier are unnecessary if LTE-A primary and secondary carriers are well synchronized and UE can synchronize with LTE primary carrier. In addition, PHICH and PBCH of the CA secondary carrier are unnecessary if LTE primary carrier is configured to transfer corresponding information for the UE.

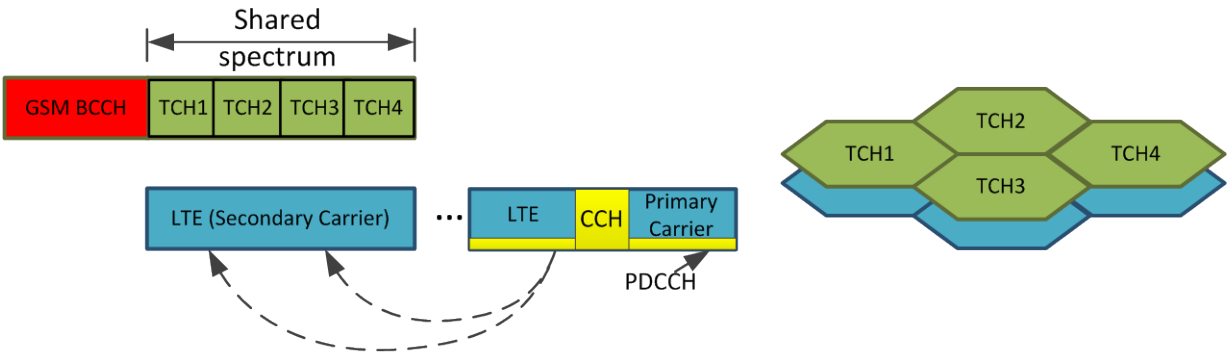

Figure 17: Transmission of GSM BCCH/TCH and LTE PDCCH in the coordinated GSM/LTE Solution.

6 CONCLUSIONS

The inefficiency of the independent operation of co-deployed RATs under system level resource partitioning motivates the development of MRJRO solutions to improve the suboptimal utilization of limited system resources. The choice of MRJRO solutions depends on the deployment strategies used by different operators. Low complexity MRJRO solutions do not require substantial modifications to existing architectures and can be implemented by defining interfaces between legacy RAT controllers (BSC/RNC) and the LTE eNB. On the other hand, advanced MRJRO solutions are enabled by the introduction of a multi-RAT controller. The introduction of a multi-RAT controller would be facilitated if operators choose to introduce the option of a centralised LTE coordinator in support of CoMP, In addition to enabling the highest performing MRJRO solutions, having a unified multi-RAT controller could also enable additional multi-RAT cooperation functions.

The work on MRJRO will be continued in the NGMN 5G project in addition to the newly-approved 3GPP study on Multi-RAT Joint Coordination (RP-132086).

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9 DELIVERABLE D8: IMPACT OF RAN SHARING ON MRJRO

9.1 Spectrum Sharing Operators

The implementation of MRJRO is not affected by RAN sharing when operators share all available spectrum; as the system has a single RAN that uses all available spectrum to serve one unified group of users (users of RAN owning operators).

9.2 Non-Spectrum Sharing Operators

When RAN sharing operators are not sharing spectrum, a single RAN uses different spectrum fragments to serve different groups of users. MRJRO is independently applied to the spectrum fragments of each operator, i.e. this scenario is equivalent to having two independent RANs that are collocated on the same site locations with no interaction between RANs.

The possibility that the split in spectrum between different operators might change in time, so that one operator has prioritised access to a certain spectrum portion, but when it is not used, it is transferred to the other operator, has not been studied extensively, However, it would seem preferable not to separate the spectrum into different carriers, but rather use one common carrier and implement the prioritisation of different portions of the spectrum within the scheduler function.