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Case with & without Carrier Aggregation

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Load-Based Traffic Steering in Multi-Layer Scenarios: Case with & without Carrier Aggregation

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***Abstract*—This paper targets at evaluating different mechanisms for providing Inter-Frequency (IF) Load Balancing (LB) in advanced multi-layer deployments. In particular, the performance of IF mobility management based on signal quality measurements is compared against a load-dependent Traffic Steering (TS) framework that triggers IF events only if load imbalance is detected. To evaluate the joint interaction of the aforementioned schemes with more advanced LB features, system level simulations have been conducted with and without assuming Carrier Aggregation (CA) capable terminals. Results have shown that although the standardized signal quality-based IF mobility management can maximize data rates, the developed framework reduces significantly the signaling overhead, at the cost of slight User Equipment (UE) throughput degradation. Nevertheless, the observed trade-off almost disappears if CA is enabled, while similar signaling gains can be achieved.**

***Keywords*—Load balancing; Mobility management; Radio Resource Control (RRC); Carrier Aggregation**

I. Introduction

Multi-layer deployments are envisaged to be the necessary network evolution for meeting the future capacity and coverage requirements. Hence, cells with different characteristics will co-exist in the same environment, also denoted as Heterogeneous Network (HetNet), providing a common pool of resources to be efficiently utilized subject to the User Equipment (UE) capabilities, power consumption, load conditions, requested service and terminal velocity. This functionality is also denoted as Traffic Steering (TS) and its target is to properly distribute traffic such as to accommodate the optimum combination of the aforementioned factors based on the network operator use cases and performance indicators.

Focusing specifically on load-based TS schemes, the majority of the state-of-art literature investigates the potentials of Mobility Load Balancing (MLB) [1] in the intra-frequency Long Term Evolution (LTE) use case, either in a single layer macrocell network [2] or HetNet deployments including low power small cells [3], also referred to as pico/femtocells. In these scenarios, Load Balancing (LB) is achieved by dynamic range extension techniques, where the downlink measurements from underutilized cells are positively biased, such as users to be steered towards them via handover (HO) executions. In the context of Inter-Frequency (IF)/Radio Access Technology (RAT) TS, different layer selection schemes are available in [4], according to which, users are redirected to the optimal cell during the Radio Resource Control (RRC) connection establishment phase. Nevertheless, the required synergy between the RRC Idle and Connected state for minimizing the signaling cost of the proposed approaches is not discussed. The concept of HO parameter auto-tuning can also be utilized for IF/RAT TS, as it is shown in [5]. However, in contrast to the co-channel case, IF/RAT measurements are not always available. In particular, they should be kept at a reasonable level since measurements gaps are required for the device to perform such measurements. High measurements rates could have an impact on the user-perceived throughput along with a potential increase of the UE power consumption. Keeping mobility management tightly coupled with TS functionalities implies that sufficient IF/ RAT measurement availability is provided, in order HOs to be triggered and a satisfactory LB performance to be achieved. However, the cost in RRC signaling might be relatively high, while jeopardizing UE power consumption.

To further enhance LB performance, Carrier Aggregation (CA) [7][8] has been introduced in the LTE-Advanced standardization. As CA UEs concurrently access the bandwidth of multiple carriers, scheduling functionalities can be further utilized for inter-layer LB. Furthermore, IF measurement availability becomes less relevant for CA UEs. Subject to their implementation, CA devices can simultaneously receive data on one carrier, while performing IF measurements on a different carrier [9].

This paper focuses on evaluating different solutions for IF HetNet LB. To tackle RRC signaling without endangering

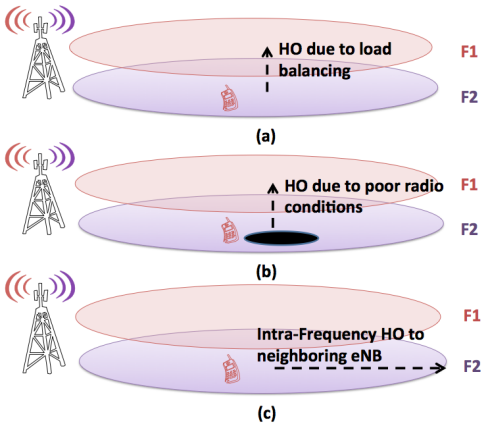

Fig. 1. Decoupling IF mobility management from TS in the RRC Connected. (a): TS-driven IF HO due to overload detection at F2, (b): Mobility driven IF HO due to coverage hole , (c): No need for any action if F2 is not overloaded and coverage is provided

UE power consumption, a low cost TS framework has been developed, that decouples IF mobility management from the LB functionalities. IF measurements are explicitly requested by the network whenever overload is detected, while the algorithm overhead is kept low by aligning the LB procedures in both RRC states. IF events (HOs/cell reselections) are classified into 2 different categories depending on the triggering cause. As it is shown in Fig. 1, an IF event is defined as mobility-driven, only if it performed due to poor radio conditions (i.e. coverage hole), while events triggered for LB purposes are classified as TS-driven ones. The performance of the designed framework is compared against the standardized signal quality handoff procedures, where IF events are triggered by exploiting the in-built load information that is available in the Reference Signal Received Quality (RSRQ) measurements. No other TS mechanism is applied and no distinction between mobility-driven and TS-driven events is possible.

System level simulations are conducted in a Long Term Evolution-Advanced (LTE-A) deployment consisting of a co-channel macro/ pico deployment at 2600 MHz, supplemented by 2 additional macrocell carriers at 1800 MHz and 800 MHz respectively. To investigate the CA impact on the aforementioned schemes, intra site CA is further enabled, meaning that CA UEs can aggregate spectrum from multiple co-sited macro carriers. Due to the deployment complexity, a heuristic approach is adopted and different configurations of the aforementioned LB mechanisms are considered.

The remainder of the paper is organized as follows. Section II outlines the IF mobility management framework for non-CA and CA users, whereas the proposed TS scheme is thoroughly presented in Section III. Simulation assumptions and results are provided in Section IV and V respectively. Finally, Section VI concludes the paper.

II. Inter-Frequency Mobility Management Framework

This section briefly discusses the standardized IF mobility management framework for both non-CA and CA terminals in the RRC Connected and RRC Idle state.

A. Physical Layer Measurements

Measurements in terms of Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ) are specified for provided mobility support in LTE/ LTE-A. RSRP corresponds to the signal strength measurement and therefore is insensitive to load fluctuations. On the other hand, RSRQ is defined as:

$$RSRQ = \frac{RSRP}{RSSI}, \tag{1}$$

where RSSI is the Received Signal Strength Indicator and comprises the linear average of the total received power including co-channel serving and non-serving cells, adjacent channel interference, thermal noise, etc [10]. The contribution of RSSI in (2) makes RSRQ partly capture load information. Hence, if properly configured, RSRQ-based mobility management can operate as a passive TS mechanism by triggering IF HOs/reselections due to the load variations between the serving and a target cell.

B. Non-CA Framework

1) RRC Connected State: RRC Connected mobility management is network-controlled and UE-assisted. UEs perform physical layer measurements and the associated reports are sent to the network, either periodically or whenever an event is triggered. Regarding the IF case, devices initiate IF measurements only if the serving radio conditions become worse than a particular threshold, also denoted as A2 event [11]. As soon as the A2 event is reported, IF mobility is activated by configuring the corresponding A3 event [11] (*neighbor becomes offset better than serving*). Given that a target cell fulfills the A3 condition for a specific time duration, also denoted as Time-To-Trigger (TTT) window, an IF HO is triggered.

2) RRC Idle State: RRC Idle UEs autonomously reselect to a neighboring cell based on the reselection rules that are broadcast in the system information. Similarly to the intra-frequency case, the cell selection S criterion along with the cell ranking R criterion [12] can be utilized for IF mobility management. Nevertheless, an alternative mechanism, referred to as Absolute Priorities (AP) [12], is available for prioritizing particular carriers during the cell reselection process. Frequency priorities are broadcast in the system information and a set of priority-based rules is evaluated for reselecting towards an IF layer. More specifically, devices camping on a lower-priority layer reselect towards a higher-priority one once the target signal strength or quality exceeds the $Thresh^{AP}_{2High}$ threshold. On the other hand, reselecting towards a lower-priority cell requires a more restrictive condition to be fulfilled, since the serving cell must drop below $Thresh^{AP}_{sLow}$ and the target to exceed $Thresh^{AP}_{High2Low}$. Note that such reselection rules are only valid for cells with different priorities. In case of equal priorities being assigned to cells belonging to different frequencies, the conventional S and R criteria are applied for evaluating the cell reselection process.

C. CA Framework

1) RRC Connected State: As aforementioned, CA devices can simultaneously access the bandwidth of multiple carriers. A set of serving cells is configured, and one of them is designated as the Primary Cell [7][8]. The PCell is responsible for all basic operations including mobility support and Radio Link Failure (RLF) supervision. HOs are solely performed at the PCell, following the non-CA handoff procedures. IF measurements are not any longer event-triggered and CA users may perform background measurements with a certain periodicity (i.e. 40 msec) [13] . Nonetheless, the A2 event can still be utilized for enabling PCell IF HOs.

Any other additionally configured cell is denoted as Secondary Cell (SCell), and it can be added, changed or removed depending on the UE measurements. Consequently, whenever an SCell event condition is met, the UE sends a measurement report via uplink RRC signaling for triggering the corresponding SCell action. An example of dynamic RSRQ-based PCell and SCell management is illustrated in Fig. 2. Situation (a) refers to the case when the PCell RSRQ is higher than the A2 threshold, $A2_{Thresh}$. Hence, PCell is kept the same regardless of the SCell radio conditions, as the event for an IF HO triggering is not yet configured. On the other hand, an IF HO is triggered for both situation (b) and (c). Cell j is now assigned

as the PCell and cell i is added as a SCell only if the SCell addition criterion is met.

2) RRC Idle State: CA is not applicable in the RRC Idle and CA UEs follow the typical non-CA framework for the cell reselection process. Thus, whenever CA users switch to the RRC Connected, the latest camping cell is assigned as the PCell, unless any TS action occurs.

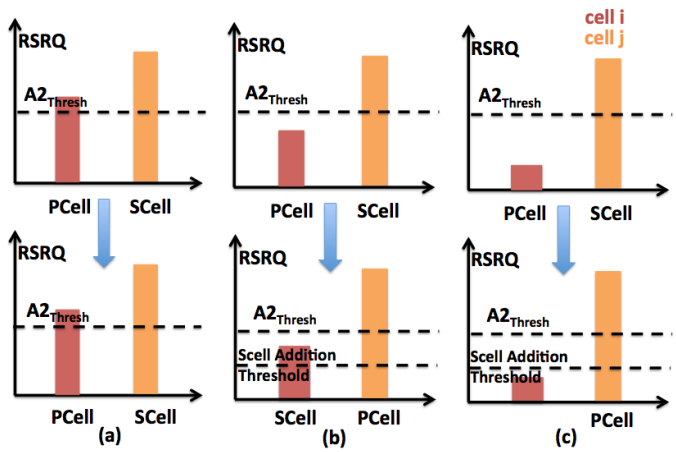

Fig. 2. Dynamic CA UE PCell and SCell management.

III. Proposed Load-Based Traffic Steering Framework

In this section, an RSRP-based LB framework is proposed, where IF HOs/reselections are primarily performed by TS-driven procedures. A relatively low $A2_{Thresh}$ is configured, while measurements are explicitly requested by the network whenever overload is detected. Consequently, measurements gaps are minimized and IF mobility management is decoupled from the TS functionality. In fact, mobility-driven IF events can only occur if the UE experiences a coverage hole; hence, the serving RSRP drops dramatically, the A2 condition is met and the terminal hands over/reselects to another frequency, regardless of the serving cell load. Minimizing the availability of IF measurements does not necessarily imply low RRC signaling and UE power consumption. In principle, the cost can be rather high, unless the TS procedures are properly aligning the RRC Idle with the RRC Connected mode. For that purpose, the designed framework exploits the switching instances of the RRC UE state machine (RRC Idle to Connected and vice versa), providing adequate synergy between the 2 RRC states.

A. Load and Composite Available Capacity Formulation

In order to provide TS support, load information for neighboring target cells should be available at the base stations. Since high Physical Resource Block (PRB) utilization does not necessarily mean overload conditions [2], the resource share of user u, f_u, is scaled by the satisfaction ratio R_t/R_u, where R_t represents the desired data rate that should on average be achieved in the cell, and R_u is the actual rate that the device experiences. Hence, the load contribution ρ_u of user u to its serving cell is defined as follows:

$$\rho_u = \min\{\frac{f_u \cdot R_t}{R_u \cdot B}, \rho_{max}\} \tag{2}$$

B refers to the cell bandwidth and ρ_{max} specifies the maximum load that a user can contribute to the cell in order to avoid situations where a single UE in poor channel conditions could declare the cell in overload. Note that for CA devices, R_u represents the aggregated data rate that the UE experiences over the multiple carriers that is scheduled. Cells periodically monitor their own load conditions $\widetilde{\rho}_{own} = \sum_u \rho_u$ and the relevant information exchange is performed in terms of Composite Available Capacity (CAC) [16]. To control TS operation, a target operational cell load, ρ_t, is specified, and CAC is expressed as below:

$$CAC = 1 - \frac{\widetilde{\rho}_{own}}{\rho_t} \tag{3}$$

TS procedures are triggered whenever $\tilde{\rho}_{own}$ exceeds a predetermined overload threshold. As load oscillations around ρ_t may repetitively trigger TS events, a hysteresis region is applied and the overload detection threshold is defined as $\rho_{high} = \rho_t + \rho_{hyst}$. Similarly, cells below the $\rho_{low} = \rho_t - \rho_{hyst}$ threshold are only willing to accept load.

B. TS upon RRC Connection Establishment

Whenever a UE switches to RRC Connected, it is requested to initiate IF measurements if overload is detected. Once the measurements reports are collected, the strongest RSRP-measured cell per frequency is selected, subject to the following constraints:

$$Q^{RSRP}_{meas} \geq A^{RSRP}_{thresh} \tag{4}$$

$$Q^{RSRQ}_{meas} \geq A^{RSRQ}_{thresh}, \tag{5}$$

where $Q^{RSRP}_{meas}, Q^{RSRQ}_{meas}$ are the performed measurements in terms of RSRP and RSRQ and $A^{RSRP}_{thesh}, A^{RSRQ}_{thesh}$ correspond to the respective thresholds that the target IF cells should satisfy. The final set of candidate LB targets is sorted in a descending CAC order and the cell with the highest value is selected. The load situation of the target cell is derived directly from CAC and if it is below the ρ_{low} threshold, an forced IF HO is initiated towards that cell for LB purposes.

Note that A^{RSRP}_{thesh} is set Δ dB higher than $A2_{Thresh}$ in order to ensure that the steered device will not perform IF measurements when is connected to the target layer. In such a manner, ping pong HOs [14] are less likely to occur and mobility performance is not compromised by the TS intervention. Finally, interference-related information for the target layer is provided via (5).

1) TS at RRC Connection Release: In the context of TS at the connection release, the dedicated priorities framework is applied, where frequency priorities are dynamically adjusted at a UE resolution, according to the exchanged CAC information [15]. Therefore, the highest priority is assigned to the least loaded carrier. Note that no additional RRC signalling is required since UE-dedicated Idle mode parameters can be provided to the device via the RRC CONNECTION RELEASE MESSAGE [11]. Dedicated priorities provide significant signalling gains, as the number of forced TS-driven HOs required for LB can be decreased. In particular, UE distributions in the RRC Idle are balanced and the probability of establishing the a new RRC connection at an overloaded cell is minimized.

The developed dedicated priorities scheme follows the same logic in terms of radio conditions constraints, implying that (4) and (5) must be fulfilled as well. Nevertheless, A_{thesh}^{RSRP} is replaced by $Thresh_{2High}^{AP}$, since $Thresh_{2High}^{AP}$ controls cell reselections towards higher priority layers in the RRC Idle state. Hence, the algorithm ensures that the redirected UE will camp at the least loaded layer, as it is the one being assigned with the highest priority.

IV. Simulation Assumptions

The implemented TS framework is evaluated by means of extensive system level simulations, assuming 0% and 50% CA UE ratio. As a reference, the RSRQ-based IF mobility management framework is used, assuming 3 different $A2_{Thresh}$ values. Mobility management in both RRC states is explicitly modeled, meaning that the related RRC delays and measurements imperfections are taken into account. Finite buffer traffic is simulated and packet arrivals are modeled as a Poisson process. The payload is negatively exponentially distributed with a mean value of 3 Mbits. 2 high traffic areas are randomly generated per site and picocells are deployed concentrically. UE density is set to 66% and users are confined in a 40m radius area, while the remaining 34% refers to UEs outside of the hotspots moving at straight line trajectories. Low mobility at 3 km/h is assumed. A detailed list of the key simulation parameters is provided in Table I.

For any case, $A2_{Thresh}$ is set equal to $Thresh_{sLow}^{AP}$, in order to to minimize the probability of RRC Idle to Connected (*and vice versa*) ping pong events. An idle-to-connected ping pong event is declared whenever a user that switches to RRC Connected, is immediately handed over to a different cell either due to radio conditions or LB purposes [6]. The RRC Idle priority assignment for the RSRQ-based LB simulations is fixed and prioritizes the 2600 MHz capacity layer ($p_{2600} > p_{1800} = p_{800}$). Measurements towards higher priority frequencies are always performed,in contrast to the ones towards a lower priority carrier, which are triggered whenever the serving quality/power drops below the $Thresh_{sLow}^{AP}$ threshold.

With regards to the applied CA configuration, CA UEs support a single SCell. The associated RSRQ-based criteria for adding, removing or changing a SCell are outlined in Table II. In particular, a relatively low threshold of -16 dB is set for SCell additions in order to exploit CA as much as possible. If more than one cells meet the SCell addition criterion, the highest RSRQ-measured cell is selected. The SCell removal threshold is set 2 dB lower, avoiding repetitive additions and removals of the same SCell due to RSRQ flunctuations. Finally, a SCell change event is also defined, according to which, the serving SCell is changed whenever a 3 dB stronger neighbor IF cell is detected. Note that TS-driven actions are only applied on the PCell, while the SCell decisions are taken independently based on the aforementioned criteria. Scheduling across the macro carriers is performed jointly, by using a modified proportional fair metric, also denoted as cross-Component Carrier (CC) scheduling [17] that enhances fairness between legacy and CA users. Conventional proportional fair scheduling is applied, if CA is not supported.

The Key Performance Indicators (KPIs) for the conducted study are the average UE throughput and the overall HO rate, defined as the absolute number of HOs averaged over the simulation time and the number of users (*including both intra-frequency and IF HOs*). As IF measurements are more relevant for non-CA devices, 2 additional KPIs have been explicitly utilized for the simulation campaign with 0% CA terminal penetration. To provide an indication of the potential impact on measurement gaps and UE power consumption, the Cumulative Distribution Functions (CDF) referring to the measured RSRQ range and the network cell load are used.

TABLE I. System Simulation Parameters

Parameter	Value
Scenario	3GPP Hexagonal grid (7 sites, 3 cells per site)
ISD	500m
Carrier Frequencies	800MHz, 1800MHz, 2600MHz
Bandwidth	10 MHz, 10 MHz, 20 MHz
Number of UEs per macro area	100
Number of picocells per macro area	2
Hotspot UE Density	66%
CA UE Ratio	0%, 50%
Transmit Power	43 dBm (macro), 30 dBm (pico)
Shadowing Standard Deviation	8 dBm (macro), 10 dBm (pico)
Shadowing Correlation Distance	50 m (macro), 13 m (pico)
Antenna Configuration	1x2
Traffic Type	Finite Buffer
Packet Size	3 Mbits
Intra-Frequency HO	RSRP-based A3 event
$A2_{Thresh}$ (TS case)	-110 dBm
$A2_{Thresh}$ (RSRQ case)	-12, -14, -16 dB
IF mobility-driven HO (RSRQ case)	RSRQ-based A3 event
IF mobility-driven HO (TS case)	RSRP-based A3 event
A3 Offset	3 dB (Intra-HO), 4 dB (Inter-HO)
HO execution Timer	0.15 sec
SCell Addition Configuration Delay	0.05 sec
TTT window	0.4 sec (Intra-HO), 0.5 sec (Inter-HO)
Measurements Error	1 dB
L3 Filtering Factor	4
R_t	{3,6}Mbps for {0%,50%}CA UE ratio
ρ_t	0.8, 0.6, 0.4, 0.35, 0.2
ρ_{hyst}	0.1
Idle-to-Connected Transition Time	0.1 sec
Connected-to-Idle Transition Time	1 sec

TABLE II. SCell Event Definition

Scell Action	Event	RSRQ Value (dB)
Addition	A4: target becomes better than threshold	-16
Removal	A2: serving becomes worse than threshold	-18
Change	A6: target becomes offset better that SCell	3

V. Simulation Results

Fig. 3 illustrates the average UE throughput for the case when only CA devices exist in the network. More specifically, we observe that the $A2_{Thresh} = -12dB$ configuration outperforms any other simulated setup, since it provides adequate IF measurement availability for exploiting the in-built load information that RSRQ carries. Although $A2_{Thresh} = -16dB$ performs the worst for all offered traffic conditions, the performance gap between the -14 dB and -12 dB case increases at lower traffic demands. This effect is explained by the AP behavior in the RRC Idle. At lower load conditions, the $Thresh_{sLow}^{AP} = A2_{Thresh} = -14dB$ threshold is not high enough for triggering reselections towards lower priority frequencies. Therefore, the 1800 MHz and 800 MHz carriers are gradually being underutilized. UEs camp at the prioritized 2600 MHz frequency and they establish their RRC connection at the same carrier, whenever they switch to the RRC Connected state. Although not presented, for values higher than $A2_{Thresh} = -12dB$, throughput gains saturate and

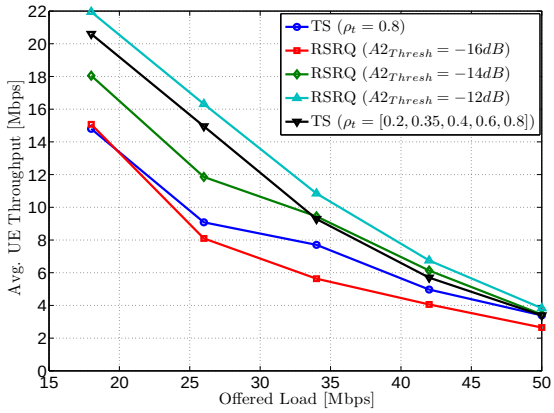

Fig. 3. Avg. UE throughput versus offered load for different LB configurations. 0% CA UE ratio is assumed.

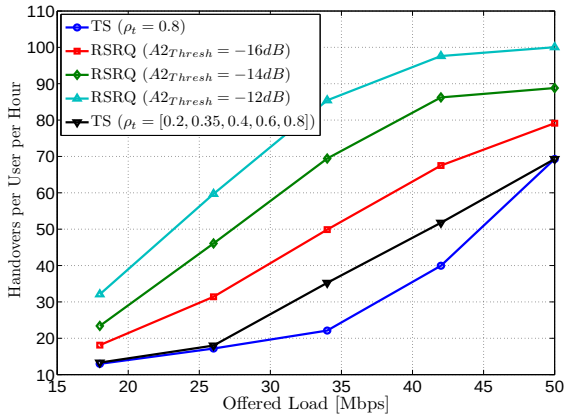

Fig. 4. HO rate versus offered load for different LB configurations. 0% CA UE Ratio is assumed.

therefore should not be recommended due to the excessive RRC signaling cost.

On the other hand, the load-based TS policy manages to follow the -12 dB RSRQ performance only if the operational target load parameter, ρ_t, is set up according to the offered load conditions (*capacity driven configuration*). This behavior is expected, as the number of TS-driven actions decrease at lower traffic demands, given that the high load $\rho_t = 0.8$ configuration is used. The R_t data rate requirement is met and therefore no overload is detected for triggering TS events. Nevertheless, the throughput gains of the $A2_{Thresh} = -12dB$ case over the capacity driven TS scheme are in the range of $\sim$7%-$\sim$15% depending on the offered traffic.

The associated HO rates are presented in Fig. 4. As expected, there is a clear trade-off between the capacity gains and the generated RRC signaling. Consequently, an $A2_{Thresh}$ of -12 dB is the most costly approach due to the relatively high number of IF HOs that are triggered by the RSRQ sensitivity to the load fluctuations. The advantage of decoupling mobility management from LB is the fact that the RRC signalling can be kept rather low. In particular, such an approach results in a 30%-60% reduction in the HO rates compared to the -12 dB RSRQ case. Considering the 2 different load-based

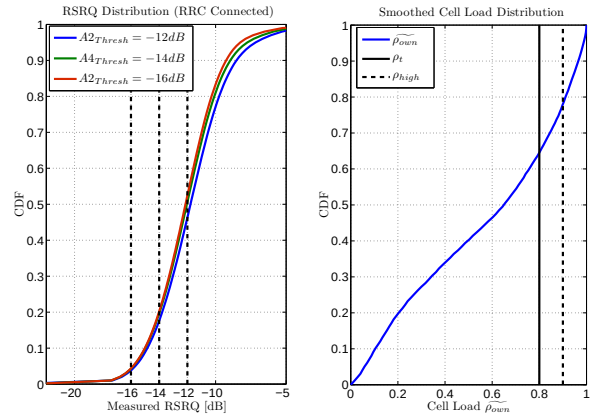

Fig. 5. CDFs for the measured RSRQ and network cell load, $\tilde{\rho}_{own}$. Depending on the selected configuration, different IF measurement availability is provided. 0% CA UE Ratio and traffic of 50 Mbps are assumed.

TS configurations, the capacity-driven one triggers more RRC signalling since LB is triggered, a fact that validates the better UE throughput performance that Fig. 3 illustrated. Finally, no difference is observed at low load conditions due to the fact that LB is provided via the RRC Idle state and the applied dynamic dedicated priority scheme.

Fig. 5 shows the CDF distributions in terms of measured RSRQ and network cell load for the 50 Mbps offered load case. Regarding the developed TS framework, recall that IF measurements are solely triggered whenever $\tilde{\rho}_{own}$ exceeds ρ_{high}. Compared to the proprietary RSRQ-based mobility, the proposed mechanisms not only maintain satisfactory data rates and decrease HO rates, but also achieve such a performance by utilizing IF measurements more efficiently. Although the presented KPIs refer to the RRC Connected state, trends are the same for the RRC Idle. In fact, dedicated priorities ensure that UEs are camping on the highest priority carrier, and therefore, no IF measurements are performed.

The CA impact on the investigated configurations is depicted in Fig. 6. 50% of CA UE ratio is assumed. Compared to the case without CA, the vast resources availability and

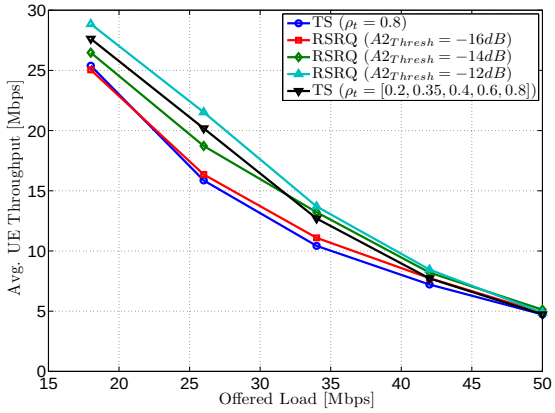

Fig. 6. Avg. UE throughput versus offered load for different LB configurations. 50% CA UE ratio is assumed.

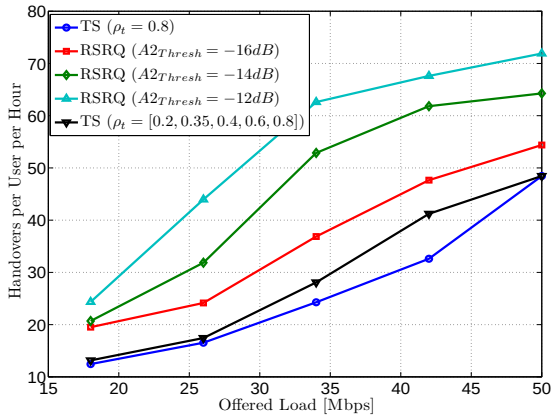

Fig. 7. HO rates versus offered load for different LB configurations. 50% CA UE ratio is assumed.

the larger transmission bandwidth significantly boosts the system performance at low load. At high traffic demands, gains saturate and the benefits come from the increased multi-user diversity. Moreover, CA diminishes the performance dependency on the IF measurements. Fast access to an overlay IF cell is achieved by means of SCell additions for UEs with CA capabilities. Apparently, the $A2_{Thresh}$ effect is only visible at low traffic demands and derives primarily from non-CA users. At higher offered load conditions, all $A2_{Thresh}$ cases behave the same, since the scheduler improves the resource allocation fairness between the 2 different UE categories, maintaining an acceptable performance for non-CA devices. Additionally, CA UEs empty their buffers at a faster rate, releasing resources to be utilized by the legacy terminals. In such a manner, any potential lack of IF measurements for legacy UEs is compensated by the CA scheduler. At the meanwhile, offloading towards the picocells is not compromised; as the RRC Idle mechanisms facilitate that purpose.

Finally, Fig. 6 shows the HO rates for the 50% CA UE ratio case, where it is rather visible that the same gains in terms of HO reduction are maintained by the TS framework. Compared to the corresponding 0% CA UE ratio results, lower rates are now observed. This behavior is an outcome of the finite buffer traffic model as the downlink buffers empty faster and the time that a UE spends at the RRC Connected state is reduced. Note that this plot does not include any SCell-related overhead. In principle, the RRC signaling is dominated by the SCell event configurations and minor differences between the different setups has been observed.

VI. Conclusions

This paper aimed at evaluating different solutions for IF LB in multi-layer HetNet deployments. A load-based TS framework has been developed and compared against the proprietary IF mobility mechanisms based on signal quality. In fact, the latter can passively distribute the load across the different layers, given that sufficient IF measurement availability is provided. Irrespective to the offered load conditions, an A2 threshold of -12 dB facilitates that purpose; however, the cost in terms of HOs and IF measurement rates is relatively high. The implemented LB framework explicitly triggers IF measurements whenever overload is detected. Compared to the RSRQ-based -12 dB configuration, physical layer measurements are more efficiently utilized, achieving significant overhead reduction and potential UE battery savings. In particular, HO events are reduced up to 30%-60%. However, the derived gains are traded-off by a slight throughput degradation in the order of ∼7%-∼15%, depending on the offered load conditions. Given that CA is further enabled, the UE performance dependency on the IF measurement availability decreases significantly and load imbalances can be compensated by the scheduler. Nonetheless, CA makes the proposed TS framework even more attractive as the aforementioned trade-off diminishes, while the signaling gains in terms of HO rate reduction remain the same.

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