Signaling Analysis for Multi-Radio Management

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***Abstract*—Increasing bandwidth demand from mobile Internet applications and the existence of 2G, 3G and soon 4G equipment in operators' networks forces them to implement an efficient resource management over all available radio access technologies. While such a multi-radio management will certainly improve resource utilization and allows reducing local hot spots, it comes at the cost of additional signaling load. In this work, we present an analysis of the signaling requirements of a multi-radio management in the fixed part of an operator's network. The signaling load for multi-radio access selection in different system architectures and for different signaling concepts is evaluated, quantified and compared. This analysis permits to conclude on the best-suited implementation strategy for co-located GSM, UMTS and LTE networks.**

I. Introduction

Network operators are faced with a challenge to provide more air interface and backhaul capacity due to the steadily increasing traffic volume from mobile Internet applications. This development entails investments to upgrade network infrastructure and to integrate new air interface and backhaul technologies. Multiple radio access technologies (RAT) will hence be combined into heterogeneous networks. In locations in which more than one RAT is available to serve a user, an overarching resource management function is required to achieve an efficient utilization of the radio resources. Its main function is to select the most appropriate RAT, taking into account parameters such as type of the requested service, user and operator preferences, signal quality, current load status, etc. The need for timely retrieval of this information requires the introduction of additional signaling flows. Depending on the resource management architecture, signaling load is increased on the air interface or in the fixed network or both.

While an analysis of additional air interface signaling has been conducted in [1], we present an analysis of the signaling requirements in the fixed part of the network, including the backhaul links of an LTE access network. We determine the signaling requirements of a largely centralized and a completely distributed resource management scheme of a multi-RAT system at the example of the so-called *Multi-Radio Management (MRM)* concept [2]. The distributed deployment alternative is preferred by 3GPP standardization, given that it does not require new network elements and it respects the functional split between radio-specific functions in the access and radio-agnostic functions in the core network.

The remainder of this paper is organized as follows: Section II describes the MRM concept and its signaling flows. Section III provides a signaling load analysis and derives formulas for two different network architectures. In section IV, system-level simulations of the air interface are used to determine the relevant parameter ranges for the previously derived formulas for two different access selection strategies. Section V then determines the signaling load on the respective backhaul links based on the results of previous sections . Finally, section VI draws conclusions.

II. Multi-Radio Management

MRM incorporates a multi-radio resource and mobility management, allowing for intelligent network-centric access selection, seamless handovers and optimized load balancing over a number of different kinds of access networks, including 3GPP and non-3GPP networks.

A. System Architecture

The MRM architecture consists of three different functional entities as depicted in Fig. 1. It follows the same principle of abstraction as presented in [3] and is thus built up by a technology-specific part and a part containing generalized functions that are identical for all RATs. The MRM-TE is located on the user terminal and provides inter-system measurement functions and an initial access selection algorithm that is used as long as the terminal has not yet established a connection with the access network. The MRM-NET is located in the access network and is associated with all active users within its service area. It communicates with MRM-TE and is located on top of the already existing radio resource and

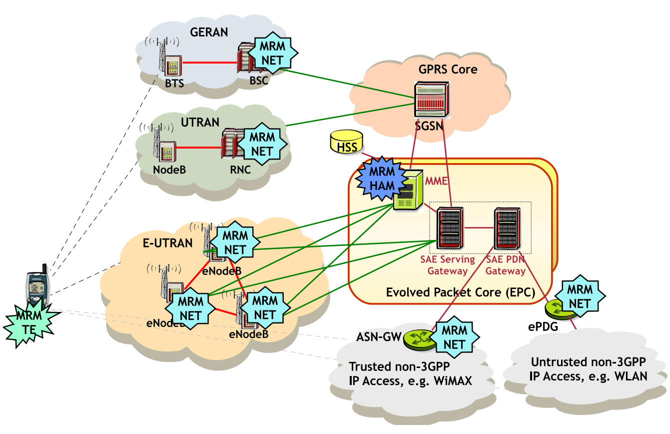

Fig. 1. Sample MRM architecture

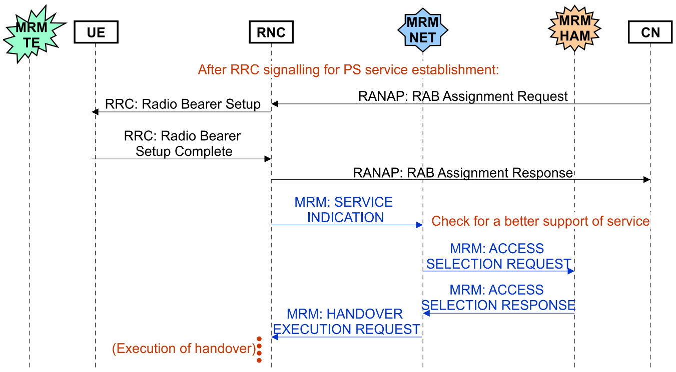

Fig. 2. Access selection at session establishment in UMTS

mobility management functions of the respective RAT, in order to be able to request measurement reports from user terminals and to trigger inter-system handovers. The main component is the *heterogeneous access management* function (MRM-HAM), which takes access selection decisions based on various input parameters such as link performance, resource usage (e. g. cell load) and availability measurements.

Different deployment alternatives exist regarding the location of the MRM entities in the network. One such alternative with a central MRM-HAM located in the core network is depicted in Fig. 1. The MRM-HAM function can likewise be distributed over the access networks and is then co-located with MRM-NET, e.g. on a BSC, RNC or eNodeB node. For scalability reasons, MRM-HAM does not maintain per-user state and only becomes active after being triggered by MRM-NET. Possible triggers are a decrease of link quality below a predefined thresholds, a potential blocking of a new or dropping of an ongoing session or, more generally, every establishment of a new radio bearer.

B. MRM Signaling Flows over backhaul links

An example of the integration of MRM in the signaling flow at radio bearer setup in UMTS is given in Fig. 2. After a Radio Access Bearer setup is completed, MRM-NET receives a service indication and triggers an *access selection (AS) request* being sent to MRM-HAM.

The processing of Access Selection requests usually is time-critical, especially if it occurred due to degrading radio channel quality. To be able to make reliable AS decisions for a given user, MRM-HAM requires up-to-date information about load levels in potential candidate cells. This information can be retrieved on-demand at the time the AS request is received (further denoted as *pull* approach), or it can be provided proactively where MRM-HAM is kept informed about resource usage in all cells of its scope (further denoted as *push* approach). While the first can cause additional delay in the processing of an AS request, the latter can lead to higher signaling load due to unnecessary status updates when no AS decision needs to be taken. There is thus a fundamental trade-off between processing delay of AS requests and the signaling volume generated between MRM-NET and MRM-HAM.

TABLE I
PARAMETERS & MESSAGE RATES FROM SIMULATION

Symbol	Description	Value
α	AS request rate of single cell	0.1 - 6 msg/s
λ	Load update rate of single cell	0.1 - 2 msg/s
λ_{RC}	Update message rate of radio controller	2.0 msg/s
λ_{eNB}	Update message rate of an eNB	0.6 msg/s
C_{RC}	Cells per radio controller	99
C_{eNB}	Cells per eNB	3
N_{eNB}	eNB nodes per RNS	33
K_{LTE}	Direct neighbor cells of an eNB	9
K_{RAT}	eNB neighbor cells in other RATs	12
M_{C}	Neighbor eNB nodes to a given cell	4
M_{eNB}	Neighbor eNB nodes to a given eNB	6

III. Signaling Load Analysis

In our signaling load analysis we concentrate on two basic network topologies. In a first scenario, we consider a co-located GSM/EDGE and UMTS/HSDPA network. We assume the MRM-NET entities to be located on the respective radio controllers, i. e. the BSC in GSM and the RNC in UMTS. For the location of MRM-HAM, we consider a centralized alternative with a single MRM-HAM device in the core network and a decentralized alternative with the MRM-HAM functionality being distributed to the radio controllers. In a second scenario, we extend the topology by a co-located LTE access network, where the MRM-NET is situated on the eNodeB.

A. Scenario 1: Co-located GSM and UMTS access networks

We evaluate and compare MRM signaling load as the message rate from and to a single radio controller. The signaling consists of access selection requests being sent to the MRM-HAM and the corresponding response messages. Depending on whether cell status information is proactively provided (*push* approach) or reactively retrieved (*pull* approach), the signaling load further includes load request and load update messages. Obviously, a *push* approach is beneficial if frequent access to cell load information is expected, whereas a *pull* approach is better suited if access selection requests occur less frequently. This consideration will be further discussed in section V, after the significant parameter ranges have been determined by means of simulation.

1) Push vs. Pull with central MRM-HAM: The signaling message rate from and to a radio controller in the first setup with proactive load updates and central MRM-HAM entity can be given to:

$$\Omega_{\text{C,push}} = 2 \cdot \alpha \, C_{\text{RC}} + \lambda_{\text{RC}} \tag{1}$$

where λ_{RC} specifies the rate at which a radio controller updates load information of its cell to the MRM-HAM in the core network. α denotes the frequency of access selection events per cell. For each AS event, there are an AS request and response message being sent over this link. See Tab. I for the remaining parameters.

For the *pull* strategy, the signaling is composed of AS request and response messages due to access selection events in one of the cells served by the radio controller. Furthermore, every AS event in one of the cells of a radio

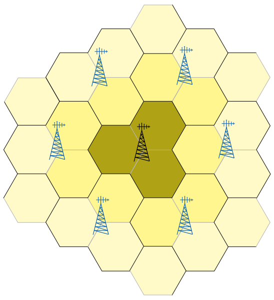

Fig. 3. Cell layout and neighbor relations for LTE

controller in a neighbor RAT triggers a load request and load update message being exchanged between MRM-HAM and the neighboring MRM-NETs. If we assume that a radio controller includes the current status of all its cells in the AS request message, the resulting message rate per radio controller is:

$$\Omega_{\mathrm{C,pull}} = 4 \cdot \alpha\, C_{\mathrm{RC}} \tag{2}$$

For simplification, we do not include boundary effects between neighbor radio controllers of the same RAT, given that radio controller service areas consist of at least several dozen cells.

2) Push vs. Pull with distributed MRM-HAM: In case of a distributed MRM-HAM, access selection algorithms are implemented at radio controller level. The BSC respectively RNC can thus immediately react to access selection events in its cells. Consequently, no signaling is required for AS requests. The MRM signaling for a given radio controller thus only consists of load updates sent to and received from radio controllers of neighbor RATs:

$$\Omega_{\mathrm{D,push}} = 2 \cdot \lambda_{\mathrm{RC}} \tag{3}$$

Similarly, for the pull strategy, signaling load is composed of load request and response messages of the local radio controller, and load request and response messages resulting from an access selection event in a cell of a neighbor RC:

$$\Omega_{\mathrm{D,pull}} = 4 \cdot \alpha\, C_{\mathrm{RC}} \tag{4}$$

Although the signaling load here equals $\Omega_{\mathrm{C,pull}}$, this does not hold if more than two co-located systems are considered.

B. Scenario 2: Co-located GSM, UMTS and LTE RAN

We now consider an extended network topology with co-located GSM/EDGE, UMTS/HSDPA and LTE network. For LTE, we assume a certain number of N_{eNB} nodes which together cover the same area as the co-located GSM or UMTS network. As before, the MRM signaling load is evaluated as the message rate to and from a single GSM or UMTS radio controller. As an additional metric, we also derive expressions for the message rate on the backhaul link of an eNodeB.

Given that the service area of a single eNodeB is significantly smaller than for an RNC or BSC, we have to take boundary effects between neighbor eNB nodes into account. Figure 3 shows eNodeBs in a hexagonal cell layout. Each eNB has $C_{\mathrm{eNB}} = 3$ cells. In our setup, for any eNB, there are K_{LTE} neighbor LTE cells and another K_{RAT} neighbor cells in each of the co-located RATs. In addition, for any given LTE cell, its direct neighbor cells are served by the M_{C} direct neighbor eNodeBs. Finally, each eNB has M_{eNB} direct neighbor eNB nodes. While the various parameters here are directly inferred from the hexagonal cell layout (see Tab. I), it is possible to use more accurate numbers of neighbor relations derived from an actual geographic network topology.

1) Push vs. Pull with central MRM-HAM: In case of the *push* strategy, the signaling load on a single radio controller is not affected by the additional co-located LTE system. The signaling load $\Omega_{\mathrm{C,push,LTE}}$ is thus identical to equation 1.

For on-demand retrieval of cell status information, the signaling load towards one RNC or BSC from equation 2 is increased by load request and response messages from and to MRM-HAMdue to access selection events in one of the co-located LTE cells:

$$\Omega_{\mathrm{C,pull,LTE}} = 4 \cdot \alpha\, C_{\mathrm{RC}} + \alpha\, C_{\mathrm{eNB}}\, N_{\mathrm{eNB}} \cdot 2 \tag{5}$$

For the LTE backhaul link, it is expected that signaling messages sent over the S1 and X2 interfaces are transmitted over the same physical link of the backhaul network. They are therefore not further distinguished. The message rate on the LTE backhaul link for the *push* approach, $\Theta_{\mathrm{C,pull,LTE}}$, can thus be given as the sum of the load updates and the access selection signaling of a single eNodeB:

$$\Theta_{\mathrm{C,push}} = \lambda_{\mathrm{eNB}} + 2 \cdot \alpha\, C_{\mathrm{eNB}} \tag{6}$$

The average message rate for the *pull* strategy consists of

- AS request and response messages from/to an eNodeB,
- load request and update messages due to AS requests in the K_{LTE} neighbor LTE cells, and
- load request and update messages due to AS requests in the K_{RAT} neighbor cells of GSM, respectively UMTS

In summary, this yields an average MRM message rate of:

$$\Theta_{\mathrm{C,pull}} = 2 \cdot \alpha\, C_{\mathrm{eNB}} + 2 \cdot \alpha\, K_{\mathrm{LTE}} + 4 \cdot \alpha\, K_{\mathrm{RAT}} \cdot 2 \tag{7}$$

2) Push vs. Pull with distributed MRM-HAM: Similar as before, we consider a decentralized MRM-HAM, which is distributed over BSC, RNC and eNodeBs. For the *push* strategy, equation 3 is extended by load updates between radio controllers and eNodeBs, as well as between eNodeBs:

$$\Omega_{\mathrm{D,push,LTE}} = 2 \cdot \lambda_{\mathrm{RC}} + \lambda_{\mathrm{RC}}\, N_{\mathrm{eNB}} + \lambda_{\mathrm{eNB}}\, N_{\mathrm{eNB}} \tag{8}$$

In the *pull* approach, a radio controller now has to take the cell status of the co-located and neighboring LTE cells into account. For each access selection event, the MRM-NET needs to query each of the M_{C} eNBs that serve the LTE cells adjacent to the cell in which the access selection event occurred. In addition, a radio controller retrieves a load request for every access selection event in one of the co-located LTE cells:

$$\Omega_{\mathrm{D,pull,LTE}} = 4 \cdot \alpha\, C_{\mathrm{RC}} + 2 \cdot \alpha\, C_{\mathrm{RC}} M_{\mathrm{C}} + 2 \cdot \alpha\, C_{\mathrm{eNB}}\, N_{\mathrm{eNB}} \tag{9}$$

In a decentralized MRM architecture, update messages need to be exchanged among neighboring eNodeBs and between

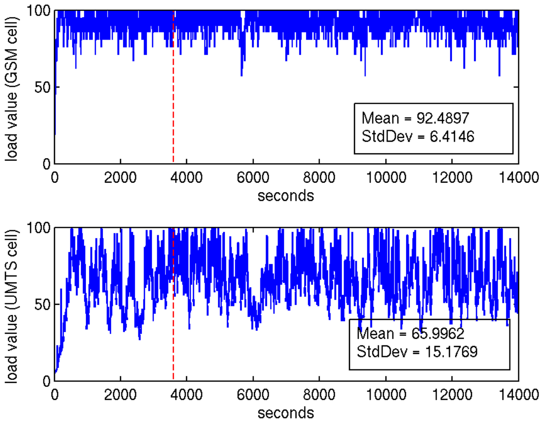

Fig. 4. GSM and UMTS load traces of a single cell

eNodeBs and the radio controllers of GSM and UMTS. Hence, the message rate on the eNodeB backhaul for the *push* approach is:

$$\Theta_{\mathrm{D,push}} = \lambda_{\mathrm{eNB}} \left(2\, M_{\mathrm{eNB}} + 2\right) + 2 \cdot \lambda_{\mathrm{RC}} \qquad (10)$$

For the *pull* strategy, signaling load is composed of the load requests and update messages after an AS request in:

- one of the K_{LTE} neighbor LTE cells of an eNodeB
- one of the K_{RAT} co-located cells of GSM or UMTS
- one of the C_{eNB} cells of the eNodeB, where status information is requested from the $M_{\mathrm{C}} - 1$ direct neighbor eNodeBs and the radio controllers of the other RATs

In summary, the resulting signaling load can be given to:

$$\Theta_{\mathrm{D,pull}} = 2\,\alpha\, K_{\mathrm{LTE}} + 4\,\alpha\, K_{\mathrm{RAT}} + 2\,\alpha\, C_{\mathrm{eNB}}\, (M_{\mathrm{C}} + 1) \quad (11)$$

IV. MRM Simulations

In the previous section, general expressions for MRM signaling load in a co-located GSM/UMTS/LTE system have been derived depending on the parameters given in Tab. I. While some of these parameters can be directly inferred from a given cell layout, the rate of access selection events α and the load update rates λ, λ_{RC} and λ_{eNB} cannot be determined as easily.

In order to identify the significant value range of these parameters, a number of system-level simulations of multi-RAT scenarios with MRM have been conducted. The simulation environment is described in [2], [4] and contains detailed models of GSM/EDGE and UMTS/HSDPA radio access technologies. The particular simulation parameters are given in Tab. II. An appropriate model for LTE has been realized by approximation. The simulations capture the relevant effects on the air interface and permit to quantify the rate of access selection events and the load variation of a cell. The next two subsections now discuss the AS rates and load variations in the simulation for two different access network selection strategies. While the overload mitigation strategy is rather conservative, the load balancing access selection strategy tries to continuously optimize load distribution over all RATs and thus leads to a significantly larger signaling load. For a more in-depth comparison of different access selection algorithms, it is referred to [4], [5]. In section V, the resulting signaling load for the observed value ranges is evaluated using the equations from section III.

TABLE II
Simulation Parameters

Parameter	Value
Systems	GSM, UMTS
Cells per system	42 (6 cell observation area)
BS-to-BS distance	2400 m
User mobility	Pedestrian, Vehicular
UMTS: max. TX power	43 dBm
GSM: max. TX power	30 dBm
GSM: number of time slots	21
Radio Propagation	COST 231-Walfish-Ikegami path loss
Voice traffic	Poisson, 120 s avg. duration, 12.2 kbps
Data traffic	WWW, best effort, see [6]

A. Overload mitigation strategy

As the first MRM strategy, an overload mitigation use case has been investigated. In case of a congestion in one system, users are transferred to another system, if permitted with respect to the target cell load. Considering a voice user scenario, an AS request is issued towards the MRM-HAM whenever a user would be blocked or dropped in its currently serving RAT. In this case, MRM-HAM will determine whether an alternative serving cell is available in another RAT. The overload mitigation strategy is a conservative strategy and exhibits rather low signaling requirements, given that MRM is involved only for the generally rare blocking or dropping events. Simulation experiments have been conducted for a number of different system load levels. The following figures show results for a load range from 80 to 105 Erlang per cell, where cell denotes the sum capacity of a GSM and UMTS.

The cell load values used here range from 0 to 100 and correspond to the realtime load scale defined in [7]. For GSM, the load value is derived from the ratio of used time slots over the total number of available time slots. For UMTS, it is given by the ratio of used base station Tx power to the maximum Tx power. The cell load variation over time of a representative GSM and UMTS cell are depicted in Fig. 4. After an initial transient phase of 3600 s, the cell load varies around a constant average load. The GSM cell is observably higher loaded than the corresponding UMTS cell, which is originated by the configuration of this simulation run. Furthermore, the standard deviation of UMTS cell load variations is twice the value of the GSM cell, because of the higher dependency of the UMTS cell load metric to user mobility and interference conditions.

In the *push* update strategy, a load update message has to be sent to MRM-HAM each time the cell load has changed. Since it is impractical to send an update message at every minor cell load change, a simple low pass filtering is applied. An update message is only sent if the current load value exceeds the previously reported value by at least $\pm\, h$ counters. In Fig. 5, the corresponding per cell load update rate is given

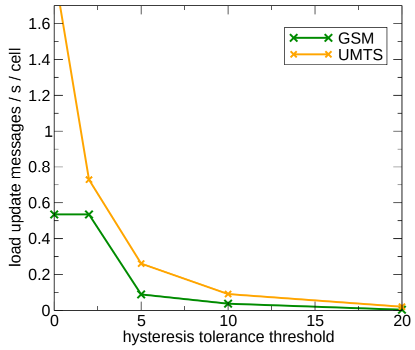

Fig. 5. Rate of load update messages over hysteresis threshold

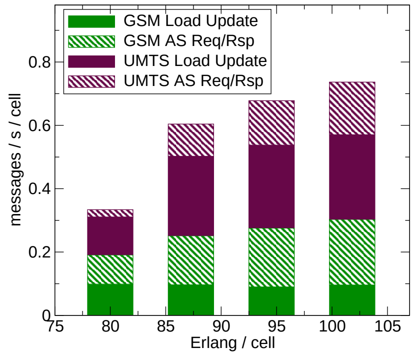

Fig. 6. Rate of load update & access selection messages of a single cell

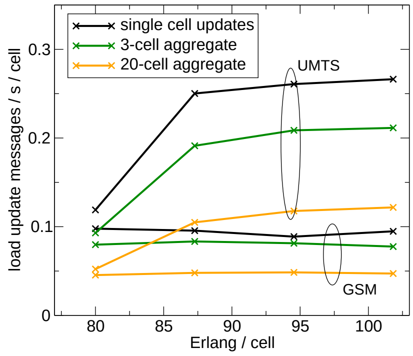

Fig. 7. Reduced rate of load updates due to aggregation in radio controller or eNB

over an hysteresis threshold h, i. e. a decreasing precision with respect to the load values that are used in the access selection decision. The values for $h = 0$ represent the message rates that would result if no filtering was applied. The message rate drops quickly with increasing imprecision and goes into saturation around a hysteresis threshold of ± 10. In GSM, due to the limited number of time slots considered here, the smallest granularity of load changes is $1/21$ and therefore no decrease of signaling load can be observed for threshold values smaller than 5. Evaluations have shown that a threshold of $h = 5$ constitutes a reasonable trade-off between imprecision and message rate and will thus be used in the following.

Figure 6 puts the amount of load updates in perspective to the amount of AS request and response messages. The 95% confidence intervals in Fig. 6 and Fig. 7 are less than 3% around the mean and have been omitted for clarity. For GSM, load update signaling stays fairly constant over the given load range, which is caused by the throughout high load handled by the GSM system in our simulation scenario. Since UMTS still has spare capacity for a total offered load of 80 Erlang, a significant increase in both load update and AS Request signaling can be observed. The rate saturates around a load of 100 Erlang, when both RATs start to be in an overload situation. Again, it can be observed that UMTS exhibits a significantly higher number of load updates compared to GSM.

The cell status information for a set of cells is assumed to be available at BSC and RNC level, respectively. In contrast to AS request messages that require timely processing, status information of the cells controlled by an RNC or BSC can be aggregated. Updates are thus only sent if load in one of the cells has changed significantly, and then contains status information on all cells of a given radio controller. In Fig. 7, the effect of aggregation is shown for aggregates of 3 and 20 cells, normalized on the effective update rate of a single cell. It can be seen that already moderate aggregation allows to decrease update rates to around $0.1\,\mathrm{msg/s}$, although the decrease is not proportional to the number of aggregated nodes.

In the following, the rate of the 3-cell aggregate of UMTS cells is used to approximate the load update rate of an LTE cell. For an eNodeB with three cells, the resulting load update rate is thus $\lambda_{\mathrm{eNB}} = 0.6\,\mathrm{msg/s}$. For a radio controller with $C_{\mathrm{RC}} = 99$ cells, we assume the total load update rate to be not more than $2\,\mathrm{msg/s}$, which is a reasonable value with respect to the time scale at which access selection decisions are taken.

The rate of Access Selection requests observed for this access selection strategy is in the range of 0.01 to $0.1\,\mathrm{msg/s}$.

B. Load balancing access selection strategy

As another MRM access selection strategy, the load balancing algorithm tries to achieve a fair distribution of throughput among users requesting variable bit rate services. At every establishment of a new radio bearer, MRM checks the availability of less loaded alternative cells in a neighboring RAT compared to the currently serving cell, in which case an inter-system handover would be triggered. For a typical web application, an access selection decision is thus taken at every establishment of a radio bearer, which results in much higher signaling requirements compared to the overload mitigation strategy. The load scale for best effort services is more coarse-grained and ranges from 0 to 3, corresponding to the load scale defined in [7] for non-realtime traffic. An average user bit rate of larger than 100 kbps is interpreted as a low load situation, whereas between 100 kbps and 56 kbps corresponds to medium load and down to 10 kbps denotes a highly loaded system.

Compared to the previous scenario, traffic characteristics differ significantly. Obviously, the rate of access selection requests is much higher. In addition, the load variations are more frequent due to the bursty nature of non-realtime traffic. From the simulation runs, depending on imposed system load, a maximum average rate of AS requests per cell of $\alpha = 5.8\,\mathrm{msg/s}$ and a maximum frequency of load updates per cell of $\lambda = 2\,\mathrm{msg/s}$ have been observed.

V. Results and Discussion

Tab. I summarizes the parameters that are used to determine numeric values for signaling loads on the radio controller and eNodeB backhaul links based on the analysis in section III. Figures 8, 9 and 10 depict the overall message rates per radio controller (Fig. 8, 9) and on the backhaul link of an eNodeB (Fig. 10). A significant metric to assess the relative overhead of one approach or MRM architecture over the other is the

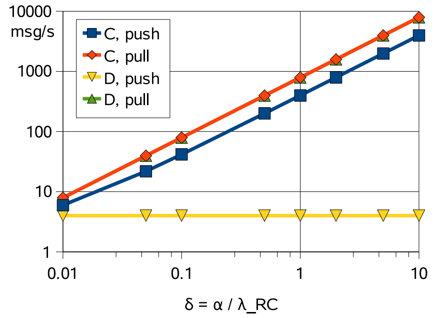

Fig. 8. Signaling load per radio controller for co-located GSM/UMTS

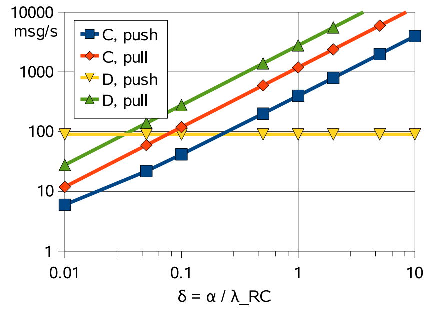

Fig. 9. Signaling load per radio controller for co-located GSM/UMTS/LTE

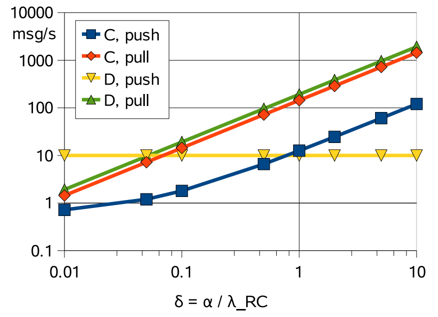

Fig. 10. Signaling load on eNodeB backhaul for co-located GSM/UMTS/LTE

ratio between α and λ, i. e. the ratio between the rate of access selection events and load updates. This ratio is plotted on the graphs' abscissas where λ_{RC} is kept constant and a value range of δ from 0.05 to around 5 corresponds to what has been observed in the simulation experiments for both MRM access selection strategies. The absolute message rates however depend on the absolute values of α and λ and on several more factors, such as the number of cells, the number of neighbor nodes, etc.

The most apparent observation from Fig. 8, 9 and 10 is that the message rate of a *push* approach with distributed MRM-HAM is independent of δ, which is caused by the straight handling of AS requests by MRM-NET without any need for inter-node signaling. The distributed *push* approach thus scales best, since the rate of load update messages can be controlled easily, while the message rate α is a consequence of the load balancing or access selection strategy and cannot be influenced directly. The central MRM-HAM with proactive load status distribution proves to be the second best alternative.

Comparing Fig. 8 and Fig. 9, it can be observed that the introduction of a co-located LTE network distinctly increases the signaling load on a BSC or RNC. The absolute message rate strongly depends on the number of co-located eNodeBs, but even in this moderate size scenario, message rates of around 100 msg/s have to be expected. Now, the distributed *push* approach performs poorly especially in low load conditions with few access selection requests. Considering the load on an eNodeB backhaul link in Fig. 10, message rates from around 10 to more than hundred messages per second can be observed. While for all central MRM-HAM approaches, most of the signaling is performed over the S1 reference point, for the distributed approaches, the messages usually need to be sent over the X2 interface. Again, due to the small footprint of an eNodeB and the large number of neighbor nodes involved in the access selection, a central MRM-HAM applying a *push* update strategy is more efficient than a distributed one over a large parameter range. As an improvement, an aggregation point within the LTE access network could be introduced, which also allows decreasing signaling overhead for co-located GSM or UMTS systems.

With respect to the delay for the processing of time-critical access selection requests, the distributed *push* approach has the clear advantage that no signaling is required to answer a request. However, the total signaling delay for the other approaches depends on access network topology and where the MRM-HAM component is located.

VI. Conclusion

In this article, an analysis of the signaling load for the access selection in a Multi-Radio Management has been presented. The message rates for centralized and distributed MRM architectures, as well as proactive and reactive cell status updates have been derived and quantified for a scenario with co-located GSM, UMTS and LTE networks. While the absolute message rates have been found to be generally uncritical for most of the relevant parameter range, the analysis shows that a distributed deployment alternative with proactive load updates scales best. It is also the least expensive solution in terms of signaling overhead for large rates of access selection requests, as for example in high load situations or for certain access selection strategies, and it provides the smallest possible processing delay for access selection requests. However, a central MRM-HAM component with proactive load updates is advantageous for small amounts of access selection requests. For the special case of LTE, the introduction of aggregation points would help to decrease message rates on the LTE backhaul links and for the GSM and UMTS access networks.

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