Reduction of Scanning Reporting Overhead in IEEE 802.16 Networks with Relays

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***Abstract*—A monitoring of signal quality must be performed in wireless networks since the users are continuously moving among base or relay stations. This is done via so called scanning procedure when a mobile station measures specific channel parameters. After each scanning, the mobile station reports the results to its serving station. This paper proposes a new method for delivering of scanning results to the serving base station if relay stations are deployed in network. The main goal of the proposal is to design a reporting technique that generates minimum management overhead during reporting. This is achieved by collecting of individual MSs' results into one message in access station. The results show reduction of scanning reporting management overhead up to 30%.**

Keywords-handover; relay station; reporting; scanning; WiMAX

I. INTRODUCTION

Mobile WiMAX, described in IEEE 802.16e [1], enables full mobility of users. User's movement among Base Stations (BSs) is enabled by handover procedure that ensures continuous connection without any requirements on user's intervention. The handover procedure can be divided into several steps [1]: Network Topology Advertisement, Scanning of MS's Neighborhood, Cell Reselection, Handover Decision and Initialization and Network Re-entry. The first two stages are used to obtain information concerning MS's neighborhood. During the scanning stage, the MS monitors channel parameters of neighboring BSs. This enables the MS to select the BS that can provide the best connection quality. While the MS is connected to the network, the scanning procedure is performed continuously during the whole time. This process can generate huge amount of management overhead. The size of management overhead is further emphasized by introducing Relay Stations (RS) into network [2]. The implementation of RSs to WiMAX network is main goal of currently developed standard known as IEEE 802.16j [3]. Basically, the RS is simplified BS which purpose is either to extend the coverage of a BS or to increase the throughput in specific area [4].

The RSs are also considered in currently originating version of WiMAX standard IEEE 802.16m [5]. The goal of this standard is to increase overall system performance to enable a support of future services and applications specified by IMT-Advance [6].

If RSs are considered, some modifications in handover procedure must be done. The handover decision might be based on the new metric that considers the specifics of RSs, such as Radio Resource Cost (RRC) proposed in [7].

The new concept of hybrid handover in Multihop Radio Access Networks (MRAN) with RSs is addressed in [8]. This paper compares reactive and proactive handover approaches from the overhead point of view. The overhead of handover and handover interruption is analyzed also in [9]. The paper proposes relay assisted hard and soft handover (RAHO, RASH) procedures. According to presented results, both techniques bring significant reduction of handover interruption. On the other hand, RASH and RSHO leads to the significant rise of overhead.

Complex modifications of handover procedure considering RSs are described e.g. in [10] − [13]. Paper [10] introduces and describes the handover procedure for a network with RSs. This paper is further extended by proposal of a new scanning procedure [14]. This proposal is further exploited in [15] where scanning overhead is reduced. The overhead reduction of scanning is achieved by joint transmission of scanning requests from all MSs by access station. It leads to the reduction of overhead up to 20%. Papers [14] and [15] analyze and optimize management of scanning (request for scanning and allocation of scanning intervals); however it does not deal with reporting of scanning results. Therefore, this paper is focused on designing of a procedure of scanning results reporting while RSs are considered in the network. Furthermore, an analysis of the overhead generated by reporting and its minimization is proposed.

The rest of paper is organized as follows. Next section explains the principle of scanning results reporting in IEEE 802.16e as well as in networks with relays. Moreover, the description of proposed technique for reduction of reporting overhead is addressed in this section. The third section focuses on an analysis of overhead generated during reporting. The results are presented and discussed in the fourth section. Last section provides our conclusions.

II. REPORTING OF SCANNING RESULTS

The procedure of scanning results' reporting differs depending on whether RSs are implemented in the network (standards IEEE 802.16j and IEEE 802.16m) or not (IEEE 802.16e) as described in following subsections.

A. Reporting According to IEEE 802.16e

If a MS is moving among BSs, it has to obtain information related to BSs in it's neighborhood in order to prepare handover from current serving BS to a new BS (denoted as target BS) that can provide better QoS (Quality of Services) to the MS. The MS has to seek a suitable neighbor BSs during a normal operation mode to fulfill handover. The procedure when a MS explores the neighborhood is called MS scanning. In conventional IEEE 802.16e standard, the scanning procedure is a time dedicated for the searching of BSs in the neighborhood within allocated scanning intervals. In these intervals, the MS determines the BS suitability to be a target BS for handover. The scanning intervals are allocated via defined MAC management messages (MOB_SCN-REQ and MOB_SCN-PSR). After the MS finishes the scanning of neighboring BSs, the results are sent to the serving BS by means of MOB_SCN-REP (or MOB_SCN-RSP) message [1].

The MS's scanning process according to IEEE 802.16e is shown in Figure 1. The MS transmits a request for allocation of scanning intervals (MOB_SCN-REQ) to the serving BS. If the scanning with association (or coordination) is required, serving BS should negotiate the association parameters with neighboring BSs. After negotiation, the serving BS sends requested information (including allocated scanning intervals) back to the MS in MOB_SCN-RSP message and MS can start with scanning of its neighborhood. The scanning results are reported to serving BS in MOB_SCN-REP message (see [1]) either periodically (periodic reporting) or after each measurement (event trigger reporting).

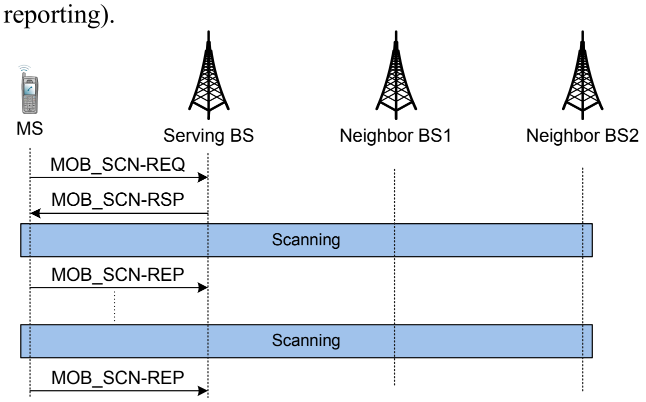

Figure 1. MAC management messages exchange during MS scanning and subsequent reporting according to IEEE 802.16e.

B. Reporting of Results via Relays

If RSs are deployed, the simplest way how to report scanning results is to retransmit the MOB_SCN-REP over all hops to the serving BS as depicted in Figure 2.

As the BS should be able to identify each single MS and determine which report belongs to which MS, the reporting message has to contain unique identification of this particular MS. The identification of MS can be done through 48-bits MSID.

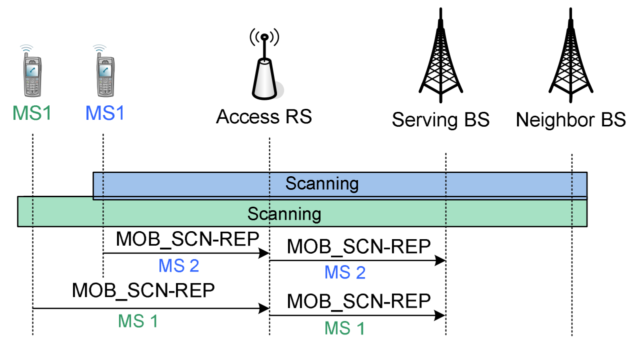

Figure 2. MAC management messages exchange for reporting of scanning results with RSs' simple retransmission.

To save the overhead, temporary MSID (Temp_MSID) enable unique identification of MS. Temp_MSID identifies the MS in frame of Access RS. Consequently, Temp_AccessRSID have to be utilized to distinguish access RS among all RSs connected to the same BS. The size of Temp_MSID field in the proposed message is set to 12 bits. Consequently, up to 4096 MSs can be currently connected to one access RS. For differentiation of the RSs within one BS's cell, the size of Temp_AccessRSID field is set to 4 bits, i.e. up to 16 RSs can be supported in a BS's cell.

C. Proposed Procedure for Reporting of Scanning Results

To minimize the resources utilized for transmission of management messages with reporting results, the reporting messages can be collected by the access RS and then retransmitted in the form of single message to the serving BS (see Figure 3).

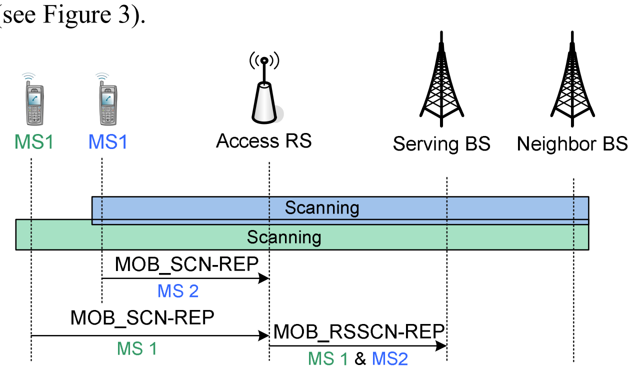

Figure 3. Proposed MAC management messages exchange for reporting of scanning results.

The simplest method is to combine the whole messages from all MSs into one message with the exception of MAC management type field. The new message is composed of management message type (8 bits), info about count of reporting MSs (8 bits) and set of messages with the same content as MOB-SCN-REP excluding 8-bits field with message type and additional including Temp_MSID and Temp_AccessRSID.

Another reduction of the overhead can be achieved by "grouping" of the MSs that carry the same reporting parameters (in the rest of paper this method is referred to as group reporting). It means group those MSs that report the same metrics (e.g. CINR, RSSI, RTD or relative delay [1]). In this case, additional reduction of overhead is accomplished by the fact that the information on carried reporting metrics is done only once for all MSs within the same group since the set of reporting parameters is unchanging as well. The proposed message is presented in Table 1.

TABLE I. REPORTING MESSAGE WITH GROUPED INFORMATION - MOB_RSSCN-REP

Syntax	Size (bites)	Notes
MOB_RSSCN-REP{		
Message Type=TBD	8	-
N_Groups	4	Number of groups of MSs with the same set of reporting metrics – N_{group}
Temp_AccessRSID	4	Temporary ID of access RS
For i=1: N_{group} {		
N_MS_in_Group	8	Number of MSs with the same set of reporting metrics – N_{MSpG}
Report Metric	8	Bitmap indication presence of certain metric (see [1]).
For j=1: N_{rMSpG} {		
Comp_NBR_BSRSID_IND	1	See [1]
N_current_BS/RS	3	Number of BSs/RSs in diversity set – N_{cur}
Temp_MSID	12	Temporary ID of MS
For j=1: N_{cur} {		
Temp_BS/RSID	4	See [1]
Reserved	4	-
Reported metrics	M x 8	See [1]
}		
N_Neighbor_BS _index	8	Number of indexed BSs/RSs; N_{ind}
For k=1: N_{ind} {		
Config_change_count	8	Only if N_{ind} >0
Neighbor_BS/RS_index	8	See [1]
Reported metrics	M x 8	See [1]
}		
N_Neighbor_BS/RS_Full	8	Number of fully addressed BSs/RSs; N_{full}
For m=1: N_{full} {		
Neighbor_BS/RS_Full	48	See [1]
Reported metrics	M x 8	See [1]
}		
TLV	var	
}		

The proposed solution can delay the delivery of scanning reports to the BS. Maximum delay introduced by this scenario is equal to the scanning reporting period of the MS with highest duration of the reporting period. However, the introduced delay is negligible if the optimum reporting period is considered (according to [16], the optimum reporting period is 0.75 s or 0.32 s for MS's speed of 10 m/s or 50 m/s respectively). It is due to the fact that a very short distance can be covered by the MS in so short time interval. Therefore, the variation of channel characteristics is negligible. Moreover, the MSs can be grouped according to the similar reporting intervals to reduce this drawback. It means to schedule the scanning results reporting of the MSs with the same intervals between reports close to each other.

III. EVALUATION OF REPORTING OVERHEAD

The overhead generated by reporting of scanning results is analytically calculated as a sum of all management information carried in the messages with reporting results.

A. Overhead According to IEEE 802.16e

The scanning results are reported to the serving BS either in periodic intervals or after each measurement in MOB_SCN-REP message (see [1] for more details). The size of this message for a MS is calculated according to the following equation:

$$OH_{16e} = \begin{cases} 40 + N_{cur} \times (8 + 8 \times M) + N_{ind} \times (8 + 8 \times M) + \\ N_{full} \times (48 + 8 \times M) + TLV, \qquad N_{ind} = 0 \\ \\ 40 + N_{cur} \times (8 + 8 \times M) + 8 + N_{ind} \times (8 + 8 \times M) \\ + N_{full} \times (48 + 8 \times M) + TLV, \qquad N_{ind} > 0 \end{cases} \tag{1}$$

where N_{cur} represents the current number of BSs in the diversity set (in case of hard handover N_{cur} is equal to 1), N_{ind} is a number of BSs addressed by index in MOB_NBR-ADV, N_{full} expresses the amount of BSs distinguished in MOB_NBR-ADV by full 48-bits address, M corresponds to the number of reported metrics and TLV represents the length of TLV encoded information. In our evaluation the length of TLV is neglected as these parameters are only optional. For cases when $N_{ind}>0$, additional 8 bits standing for "Configuration_change_count" field are inserted.

The overall overhead generated by reporting of scanning results is consequently a sum of all reporting messages over number of MSs as expressed in the next formula:

$$ROH_{16e} = \sum_{i=1}^{N_{MS}} OH_{16e_i} \tag{2}$$

where N_{MS} is the number of MSs that execute reporting.

B. Overhead According to Networks with Relays

When RSs are deployed in the network, the same message (MOB_SCN-REP) can be utilized for delivering of scanning results to serving BS. This message is transmitted by the MS to access RS and subsequently routed to the serving BS. Two additional fields with identification of access RS and reporting MS have to be included. Therefore, the length of message is increased by 16 bits (see section II-B). This pure retransmission of every reporting message over all hops between the access RS and serving BS is not effective from the overhead point of view. The overhead generated by this way can be calculated according to the following equation:

$$OH_{16j} = OH_{16e} + 16 \tag{3}$$

The overhead over all hops is evaluated as described in consequent formula:

$$ROH_{16j} = \sum_{k=1}^{N_{Hops}} \sum_{i=1}^{N_{MS}} \left(OH_{16e_{k,i}} + 16\right) = \sum_{k=1}^{N_{Hops}} \sum_{i=1}^{N_{MS}} OH_{16j_{k,i}} \quad (4)$$

where N_{Hops} represents a number of hops between the MS and serving BS.

C. *Overhead of Proposed Scanning Method*

The first way, combination of complete messages, needs to include info about a number of embedded reports (number of MSs) into new message. On the other hand, the MAC management type field is transmitted only once per all MSs. The overall size of overhead generated by pure combination of reporting messages over one hop (OH_{Comb}) is:

$$OH_{Comb} = 8 + 8 + \sum_{i=1}^{N_{MS}} \left(OH_{16j_i} - 8\right) \quad (5)$$

Equation (5) demonstrates that this reporting method saves only 8 bits per MS for $N_{MS} > 2$.

The size of overhead generated by the second proposed method (OH_{group}), i.e. group reporting is taken into account, can be calculated by the following way:

$$OH_{group} = \begin{cases} 16 + N_{group} \times \left\{ 16 + N_{MSpG} \left[\begin{array}{l} 16 + N_{cur} \times (8 + 8 \times M) \\ + 8 + N_{ind} \times (8 + 8 \times M) \\ + 8 + N_{full} \times (48 + 8 \times M) \end{array} \right] \right\}, & N_{ind} = 0 \\ 16 + N_{group} \times \left\{ 16 + N_{MSpG} \left[\begin{array}{l} 16 + N_{cur} \times (8 + 8 \times M) \\ + 16 + N_{ind} \times (8 + 8 \times M) \\ + 8 + N_{full} \times (48 + 8 \times M) \end{array} \right] \right\}, & N_{ind} > 0 \end{cases} \quad (6)$$

where N_{group} is a number of groups of MSs with the same set of reporting metrics and N_{MSpG} is a number of MSs in the same group.

The reduction ratio of reporting overhead depends on several factors: the amount of BSs/RSs (indexed, fully addressed, and current/serving), the number of reporting metrics, the amount of MSs that report simultaneously, and the number of groups of MSs with the same set of metrics. If we assume hard handover, the number of current serving BSs/RSs is always equal to one (see [1]). The amount of reported BSs/RSs (both indexed and fully addressed) depends on the number of neighbouring BSs/RSs that are scanned. The number of reported metrics varies between one and four (see [1]). The number of MSs reporting simultaneously is equal to an amount of users connected through the same access RS that perform scanning. The last parameter is the quantity of MSs' groups (N_{group}). The maximum value of this parameter ($N_{groupMAX}$) is related to the maximum number of reported metrics (according to [1], this number is 4) and can be calculated according to the following formula:

$$N_{groupMAX} = \sum_{k=1}^{n_{metrics}} C_k(n) \quad (7)$$

where $N_{metrics}$ is a number of metrics included in report per a MS and $C_k(n)$ is a number of combinations of metrics that can be reported.

$$C_k(n) = \binom{n}{k} = \frac{n!}{k!(n-k)!} \quad (8)$$

If the number of metrics is = 4 ($n=4$), then the maximum number of all combinations is 15 as evaluated by means of the next equation.

$$N_{groupMAX} = \sum_{k=1}^{4} C_k(4) = C_1(4) + C_2(4) + C_3(4) + C_4(4) = 15 \quad (9)$$

IV. RESULTS

The results of the proposal are summarized in following figures. All figures present evaluation for both reporting methods (pure combining of separated reports – OHcomb and group combining – OHgroup).

Figure 4 and Figure 5 depict an impact of a number of reported metric. The figures illustrate the results for fully addressed BS/RS (Figure 4) and BSs/RSs addressed by index (Figure 5) in MOB_NBR-ADV (see [1]). From figures can be observed that the overhead reduction is higher for lower number of reporting metrics. Figures further demonstrate that the negative impact of proposed methods is only when one MS executes reporting. Nevertheless, for more than one MS, both proposals bring a reduction of reporting overhead. The ratio of reduction is increasing with the number of reporting MSs connected to the same access RS up to 30 MSs. If there is more MSs, the overhead reduction is only marginal and saturates to the maximum value.

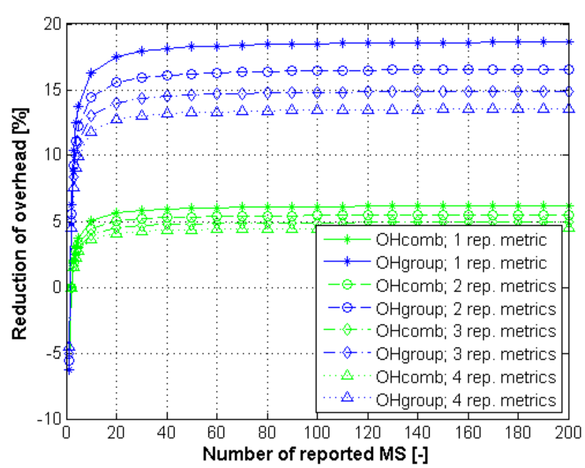

Figure 4. Reduction of reporting overhead over number of reporting MS for different amount of reported metrics for one fully addressed neighboring BS/RS.

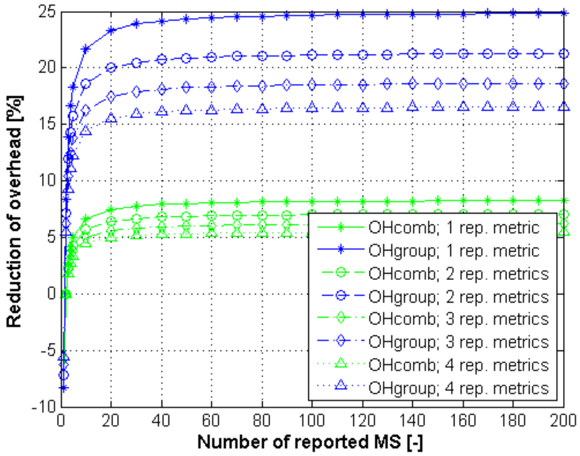

Figure 5. Reduction of reporting overhead over number of reporting MS for different amount of reported metrics for one neighboring BS/RS addressed by index.

Impact of a number of MSs' groups that report the same metrics is presented in Figure 6 and Figure 7. From analysis of figures can be derived that the effect on overhead reduction is decreasing with rising number of groups. The most significant increase is for low number of MSs. The curves that correspond to particular number of groups cannot be depicted for lower number of MSs than number of groups. This is due to the fact that each group has to contain at least one MS (e.g. if 15 groups is considered, the lowest number of MSs for which the reduction can be calculated is also 15). The results achieved by pure combination are not included in figure as it does not depend on the number of groups since the number of reported metrics is defined for each single MS.

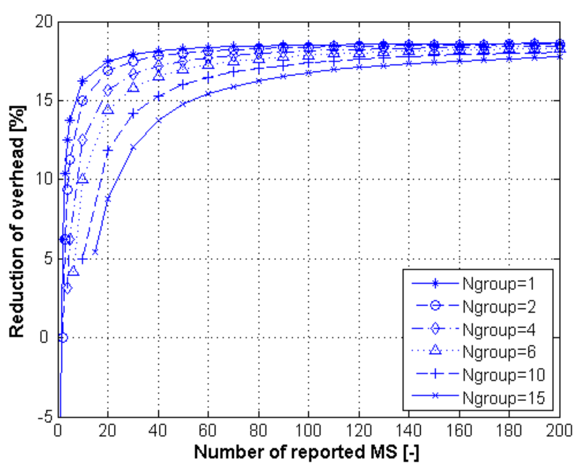

Figure 6. Reduction of reporting overhead over number of groups of reporting MSs for one fully addressed neighboring BS/RS.

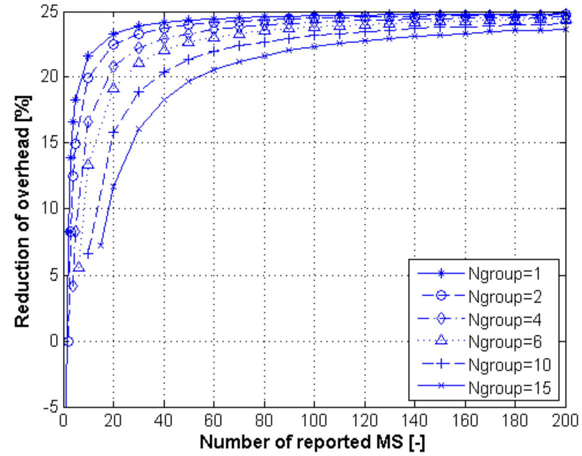

Figure 7. Reduction of reporting overhead over number of groups of reporting MSs for one BS/RS addressed by index.

The maximum achieved reduction is approximately 19% and 25 % for fully addressed BSs/RSs and BSs/RSs addressed by index respectively (as can be observed from Figure 4 – Figure 7). The insignificant rise of overhead is noticeable only in case of single reporting MS.

The results of overhead reduction over a number of reported BSs/RSs are presented in Figure 8. The number of reported neighbouring BSs/RSs assumes reporting of just one metric from 30 MSs, one serving BS/RS (current BS/RS) and between 0 and 15 indexed or fully addressed neighbouring BSs. More than 30% of reduction is achieved if only current serving BS parameters are reported. The figure shows that the efficiency is decreasing with rising number of reported BSs/RSs. The better performance is achieved by group reporting and fully addressed BSs/RSs.

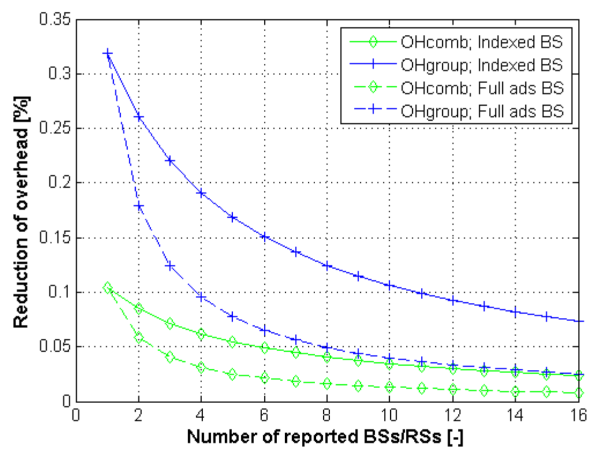

Figure 8. Reduction of reporting overhead over number of reported BSs and RSs.

The effect of overhead reduction is rising with number of reporting MSs. On the other hand, the ratio of reduced overhead is decreasing with increasing number of reported metrics, number of groups and number of reported BSs/RSs.

V. Conclusions and Future Work

This paper proposes a method for more effective delivery of results of MS's neighborhood scanning called group reporting. Proposed technique utilizes a combination of scanning reports from all MSs connected to the same access station. Scanning reports are combined in the access station in groups according to the set of reported metrics. Consequently, the new message is transmitted to the serving BS.

Effectiveness of group reporting method depends on the number of reporting MSs connected to the same access station, number of reported metrics, number of groups of MSs and number of reported BSs and RSs. The group reporting method enables to save up to 30% of reporting overhead.

The future research will tackle the analysis of another possible reduction of MAC management overhead related to the mobility support.

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