Path Selection in WiMAX Networks with Mobile Relay Stations

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Abstract—**Introduction of mobile relays into networks based on IEEE 802.16 standard brings new challenges. The paper proposes signaling mechanism for acquisition of channel state information for mobile relays and provides detail analysis of the amount of signaling overhead caused by its introduction. In addition, the investigation whether the connection of the mobile users through the mobile relays enhances the system performance is carried out. The obtained simulation results indicate that by means of mobile relays, the overall throughput can be increased and signaling overhead reduced.**

Keywords-CSI; mobile relays stations; path selection; WiMAX

I. INTRODUCTION

Over the several last years, wireless systems and technologies established themselves as one of the fastest growing and developing area in the field of telecommunications. Especially IEEE 802.16 standards, also known as WiMAX (Worldwide Interoperability for Microwave Access), have a great potential. In 2004, IEEE 802.16-2004 [1] version intended for fixed users was approved, which was followed by IEEE 802.16e [2] finished one year later. To cope with increasing users' requirements for higher data rates, new WiMAX working groups were established in 2006, i.e., IEEE 802.16j [3] and IEEE 802.16m [4]. The IEEE 802.16j version introduces Relay Stations (RS) that has two purposes; i) to enhance the system capacity and ii) to increase the network coverage. The main aim of IEEE 802.16m is to address shortcomings of already defined standards such as spectral efficiency and overhead of Medium Access Control (MAC) layer.

According to [5], three types of RSs are defined; fixed, nomadic and mobile RSs. The fixed RS (FRS) is permanently installed at the same location. Although the nomadic RS (NRS) is also fixed when operating, its position can be changed as needed. The last type of the RS, i.e., the mobile RS (MRS) is moving in similar way as Mobile Stations (MS).

When RSs are introduced into WiMAX based networks, several routes between the MS and Base Station (BS) can be found. The challenge is to select the route offering the best network's performance. In the scope of IEEE 802.16j standardization body, several proposals focus on routing issues in relay-based WiMAX networks (e.g., in [6][7]). In [6], the authors propose a signaling mechanism for efficient routing intended for IEEE 802.16j standard. Nevertheless, the best point of attachment is decided immediately after the network entry procedure and no potential changes during MS's operation are discussed. In [7], end to end routing and connection management is addressed. Besides the standardization activity, a lot of research papers dealt with routing issues in IEEE 802.16 networks with the FRSs. The common aim is to design effective path selection metrics and to propose suitable path selection algorithms for appropriate routing of data (see, e.g., [8]-[13]).

To our best knowledge, all existing works dealing with routing issues assume only the FRSs, not the MRSs. Thus, the novelty of this paper is that takes into consideration also the MRSs and analyzes their impact on system performance. The aim of the paper is twofold. Firstly, the objective is to propose signaling mechanism allowing acquisition of channel state information (CSI). If the CSI of individual routes is known, the most appropriate path between the MS and BS can be selected. As a basis, the proposal uses the signaling mechanism introduced in [11], which takes into consideration only the FRSs, and extends it for the MRSs as well. Secondly, the aim is to investigate if it is profitable to use the MRS by MSs that are in close vicinity of the MRS but not located on the same vehicle as MRS.

The rest of the paper is organized as follows. The next Section overviews MAC management messages used in the proposed signaling scheme and contemplates the assumptions considered in the paper. The proposed signaling mechanism is introduced in Section 3. In addition, the analysis of overhead introduced by signaling mechanism is addressed. The next two Sections describe simulation scenario and show the simulation results. The last Section gives our conclusion.

II. PRELIMINARIES

A. MAC management messages

In IEEE 802.16e standard, several options to obtain CSI between the BS and MS are defined. In our proposal, the BS acquires the CSI by means of MOB_SCN-REP (mobility scanning report). The MOB_SCN-REP contains the results of scanning procedure. Time allocated for the scanning and reporting period is allocated to the MS through MOB_SCN-RSP messages (mobility scanning response). Two types of reporting are specified: a) event triggered reporting and b) periodic reporting. In the event triggered reporting, the MS sends the reports after each measurement of channel parameters, i.e., CINR (Carrier to Interference and Noise Ratio), RSSI (Received Signal Strength Indicator), Relative delay and RTD (Round Trip Delay). In the periodic reporting, the reports are sent periodically.

If the MS is attached to the BS through one or more RSs, the results of scanning have to be retransmitted to the BS. One option is to simply send the MOB_SCN-REP received by the individual MSs. Nevertheless, this option generates significant amount of signaling overhead. The second option is to combine obtained scanning results by all subordinate stations into one message labeled as MOB_RSSCN-REP. The definition and structure of the MOB_RSSCN-REP can be found in [14].

Similarly as in [11], the proposal distinguishes the activity/inactivity of the MS. To be more specific, the scanning and reporting periods depend on whether the MS has data to send or not. When the MS becomes active, the bandwidth request header (in IEEE 802.16 standard labeled as BW request) is send to the BS.

B. Assumptions

The IEEE 802.16 standard specifies several physical layers. In the paper, physical layer based on Orthogonal Frequency Division Multiple Access (OFDMA) is considered. In addition, the uplink and downlink transmissions utilize the same frequency band, i.e., the Time Division Duplex (TDD) is assumed. The maximal number of hops between the MS and BS is restricted to three hops. Consequently, the MRS can be attached either directly to BS or via one FRS.

According to [5], the MRS is supposed to be placed on some kind of public traffic vehicle such as bus or tram. Hence, the MRSs can be considered as another MSs moving along the predefined trajectory (e.g., the path, along which the bus is traveling from departure to terminal station). The only difference with regard to the MS is that the MRS generates distinguishable more traffic as aggregates traffic of its subordinate MSs. In comparison with the MS, the MRS is assumed to be active all the time since its control information at the beginning of every frame must be transmitted. Consequently, no active/inactive state is distinguished as in case of MS. In addition, the MSs located at the same vehicle as the MRS are supposed to be fixed with respect to the MRS.

III. PROPOSED SIGNALING METHOD

This section firstly describes the signaling mechanism, which purpose is to obtain CSI. Secondly, the impact of MRSs in the network on the signaling overhead is analyzed. Thirdly, the path options for MSs are contemplated.

A. CSI acquiaition with Mobile Relay Stations

When the MS is attached to the FRS or MRS while in inactive state, the acquisition of CSI is done exactly in the same way as describes [11]. Hence, the scanning period is set to t_1 and reporting period is set to t_2 (see Fig. 1). Both the scanning and reporting periods (scheduled in the MOB_SCN-RSP), are derived from the speed of the MS and can occur relatively infrequently in order to save valuable radio resources. In addition to further minimize signaling overhead, the value of t_2 can be set to $n*t_1$ where n is the integer value. Nevertheless, the MOB_SCN-REP should be sent by the MS anytime if CINR between the MS and the access station (BS or RS) drops below a specific value for a certain amount of time. This principle guarantees that a handover can be made in advance. If the MSs are connected to the MRS, the MRS create single MOB_RSSCN-REP message by combining of all MOB_SCN-REP messages and retransmitted it in the direction of BS. Thus, the reduction of signaling overhead is achieved. Nevertheless, if the MS is attached to the FRS, the FRS itself simple relays the message toward the BS. This is due to the fact that the reporting intervals of individual users attached to the FRS are not necessarily scheduled at the same time intervals and to wait for all MOB_RSSCN-REP can have result in outdating of reporting information.

On the other hand, the MRS itself needs to send CSI to the BS in order to use the optimum route to the BS. As the MRS is considered to be active all the time, the value of scanning period t_3 and reporting period t_4 should be set to

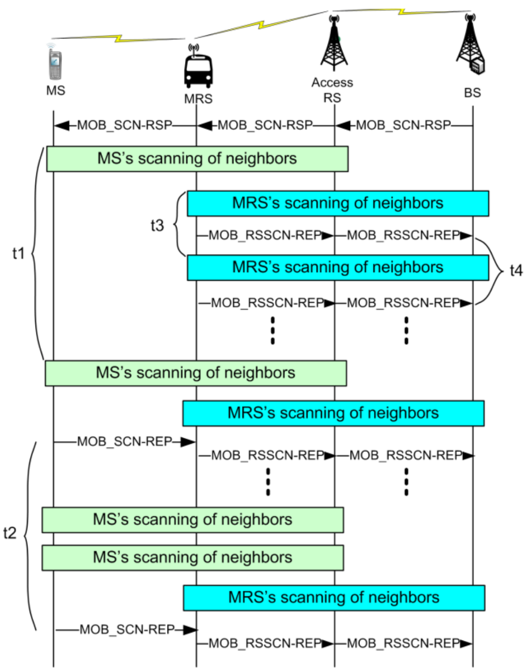

Figure 1. Scanning and reporting periods of MRS and MS (MS in inactive state).

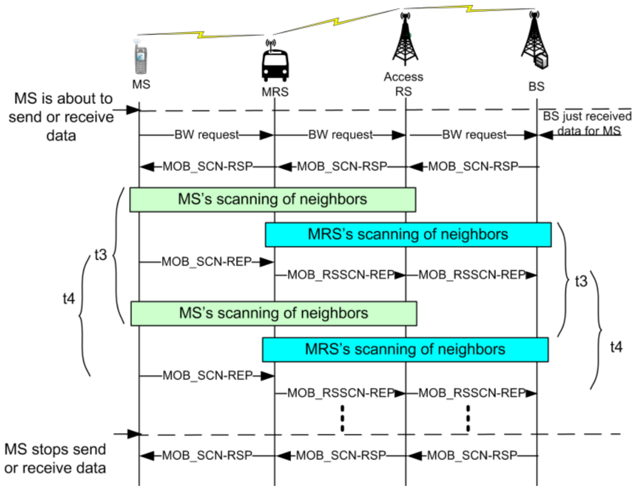

Figure 2. Scanning and reporting periods of MRS and MS (MS in active state).

much shorter values than t_1 and t_2. Thus, the up to date route between the MRS and BS can be maintained. The results acquired during the MRS's scanning interval are appended to MOB_RSSCN-REP message.

If MS becomes active, the scanning and reporting intervals should be changed accordingly in order to obtain up to date channel information (see Fig. 2). The BS learns about MS's transition from the inactive to the active state either through BW request, which originates at the side of the MS, or when the BS has some data designated to this MS (see Fig. 2). Consequently, the BS transmits another MOB_SCN-RSP message in order to schedule new scanning and reporting intervals. The MS performs scanning at t_3 interval while the reporting interval is set to t_4 similarly as in case of permanently active MRS. However, if the MS is located at the same vehicle as the MRS, the reporting and scanning intervals for the MS can remain the same as described in Fig. 1. The reason is that the MS is fixed (or slowly moving) with regard to the MRS. Thus, the variation of channel conditions is supposed to be minimal and signaling overhead can be reduced.

B. Analyzis of signaling overhead

The amount of overhead introduced by an acquisition of CSI between the BS and MSs is proportional to several parameters. The first parameter corresponds to the size of the reporting messages MOB_SCN-REP (ms_1) and MOB_RSSCN-REP (ms_2). In general, the number of MS's neighbors has direct impact on the messages size. Since the MOB_SCN-RSP message is send infrequently, its impact on the overhead is minimal and it is neglected in the paper. The second parameter is the amount of active MSs in the system (n). The third parameter is the number of hops between MS_i and the BS (noh_i), i.e., how many times the reporting messages have to be relayed to reach the BS. The last parameter influencing the overhead is the system configuration's setting (e.g., reporting period rp_i, nominal channel bandwidth, OFDMA parameters, etc.).

The overhead is composed of several parts. The first part of the overhead is caused by MOB_SCN-REP message send by the MSs to their access stations, which could be expressed as:

$$OH_{MS}[b/s] = \sum_{i=1}^{n_1} ms_1^i \times \frac{1}{rp_i(t_2)} + \sum_{i=1}^{n_2} ms_1^i \times \frac{1}{rp_i(t_4)} \quad (1)$$

where n_1 is the number of inactive users and n_2 represents the amount of active users (i.e., $n_1 + n_2 = n$). Note that message size ms_1 is expressed in bits and reporting periods in seconds. The second part of the overhead is generated by the RSs. For the MSs connected only through the FRSs, the overhead can be formulated as follows:

$$OH_{FRS}[b/s] = \sum_{i=1}^{n_{11}} ms_1^i \times (noh_i^{MS} - 1) \times \frac{1}{rp_i(t_2)} + \sum_{i=1}^{n_{21}} ms_1^i \times (noh_i^{MS} - 1) \times \frac{1}{rp_i(t_4)} \quad (2)$$

where n_{11} is the number of inactive users attached to the FRSs, n_{21} represents the amount of active users connected to the FRSs and noh_i^{MS} is the number of hops between the MS i and BS. In other words, the MOB_SCN-REP message is simple relayed to the BS as described earlier. The overhead caused by the MSs connected to the MRS and MRSs itself can be expressed as:

$$OH_{MRS}[b/s] = \sum_{i=1}^{m} ms_2^i \times noh_i^{MRS} \times \frac{1}{rp_i(t_4)} \quad (3)$$

where m is the number of MRS and noh_i^{MRS} corresponds to the amount of number of hops between the MRS i and BS. The size of MOB_RSSCN-REP varies depending on the amount of received MOB_SCN-REP sent by subordinate MSs, which could be formulated as:

$$ms_2[b] = K + (n_{22} + 1) \times (ms_1 - K) + K_1 \quad (4)$$

where K is the size of message fields that are transmitter disregarding the amount of received MOB_SCN-REP messages (n_{22}), K_1 stands for the information added by the RS in order to recognize by the BS which MSs are sending reporting information. In [14], it is demonstrated that if at least two messages are combined at the side of MRS, saving of overhead is achieved.

C. *Path selection options*

The MS can be connected either directly to the BS, to the FRS or to the MRS. The question is whether the MS situated near of the MRS (but not at the same vehicle as the MRS) can use the MRS to access the BS as indicated in Fig. 3. On one hand, the overall system throughput may be enhanced since the route via the MRS could offer better connection to the users. On the other hand, the connection through the MRS may have drawback since the route between the MS and BS can change rapidly, e.g., the advantage of attachment through the MRS is only of temporary duration. In this regard, higher number of MS's handover initialization may occur. Nonetheless, the excessive number of handovers can be mitigated by utilization of HDT (Handover Delay Timer) technique proposed in [15] which purpose is to delay handover initialization.

In addition, the signaling overhead is influenced by the MRSs' introduction. Thus, the aim of the following performed simulations is to investigate how the implementation of the MRS influences the system throughput and the amount of signaling overhead.

IV. SIMULATION SCENARIO

The simulations are done in MATLAB environment. The parameters' setting is given in Tab. 1. The simulation model is composed of one BS and eight FRSs. A deployment of individual stations is illustrated in Fig. 4. In the simulation, four MRS moving along predefined rectangular trajectories are considered (the initial position of MRSs is also shown in Fig. 4)

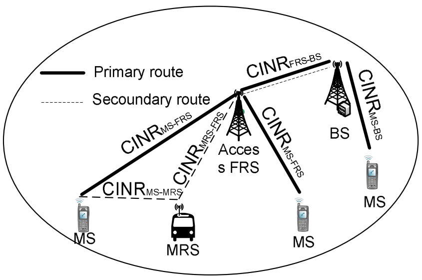

Figure 3. Path selection option for the MS.

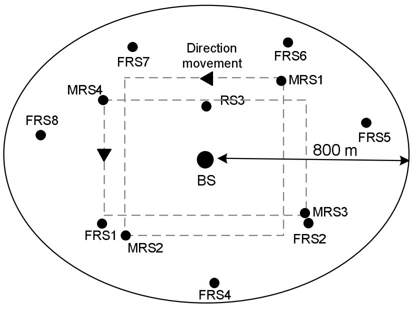

Figure 4. Deployment of RSs and MRS within BS cell.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Frequency band [GHz]	3.5
Channel bandwidth [MHz]	20
Number of MS	50
MS and MRS velocity [m/s]	10-50
Frame duration [ms]	10
BS transmit power P_t [dBm]/height [m]	43/30
FRS transmit power P_t [dBm]/height [m]	30/30
MRS transmit power P_t [dBm]/height [m]	30/4
MS transmit power P_t [dBm]/height [m]	23/2
Noise [dBm]	-100.97
Simulation time [min]	60

The MRS can be connected either directly to the BS or via one intermediate FRS. Connection through more than one FRS is not allowed due to maximum number of hops restrictions (which is up to 3 hops between the MS and BS). Additionally, attachment of MRS through another MRS is not considered.

The movement of the MSs is managed as follows. At the beginning of simulation, an initial position of each MS is randomly determined so that the MS has to be located within defined range, i.e., between 0 to 800 m from the BS. Additionally, random movement direction is determined for all individual MSs in the system. The mobile terminal is moving along straight line until the distance from the BS is equal or larger than defined BS's cell area. In such circumstance, a new direction of the MS is established. This mechanism guarantees that no MS roams out of the BS range during the simulation process.

Two path loss models taken from [16] are implemented. The first one is suitable for LOS communication and describes radio channel behavior between the BS-FRS and the FRS-FRS. The second one is assigned for NLOS communication between the BS-MS, FRS-MS, BS-MRS, FRS-MRS and the MRS-MS.

The path between the MS and BS is selected according to the minimum Radio Resource Cost (RRC) metric (more detail may be found in [17]).

The reporting period t_4, assumed in the simulation, corresponds to the optimal reporting period for active MS/MRS derived from [11]. If the MS is inactive, the reporting period t_2 is set to value of $t_4/10$ in order to minimize signaling overhead.

The system performance is analyzed in terms of system throughput and overhead generated by the MSs and MRSs. To that end, three scenarios are considered. The first scenario represents the situation when MRSs are not assumed (in the following figures labeled as "Scenario A"). Nonetheless, some of the MSs' are positioned at public traffic vehicle moving along predefined trajectories. In the second scenario, the MRSs are installed at public traffic vehicle (in the following figures labeled as "Scenario B"). Thus, the MS situated at the bus are connected to the network right through newly deployed MRS. In the last scenario, it is assumed that also MSs currently not placed at

TABLE II. HDT SETTING FOR SCENARIO C

Scenario type	HDT value [s]
Scenario C1	0.01
Scenario C2	0.1
Scenario C3	0.5
Scenario C4	1
Scenario C5	5

TABLE III. TRAFFIC MODELS TYPE

Model type	**VoIP**	**FTP**	**HTTP**
VoIP only	100%	0%	0%
Traffic Mix I	30%	30%	40%
Traffic Mix II	10%	80%	10%

the MRS can use this MRS as an access station (in the following figures labeled as "Scenario C"). Scenario C considers different values of HDT as shown in Tab. 2.

To evaluate the maximal throughput, a full queue traffic model is implemented [18]. The throughput evaluated in the paper represents a system WiMAX capacity obtained at the MAC level. Hence, the overhead introduced by higher layer protocols (e.g., network, transport, etc.) is not considered.

To estimate the amount of the signaling overhead due to reporting, the size of MOB_SCN-REP and MOB_RSSCN-REP messages are derived from [2] and [14] respectively. The activity and inactivity of MSs depend on implemented traffic models. In the simulation, VoIP only and two traffic mixes are considered as indicated in Tab. 3 (detail traffic models description can be found in [18]).

V. SIMULATION RESULTS

Fig. 5 shows the normalized signaling overhead caused by the reporting messages MOB_SCN-REP and MOB_RSSCN-REP depending on the MSs/MRSs velocity. The worst performance is obtained by Scenario A as the highest amount of overhead is generated for all traffic models. The difference in the amount of generated signaling overhead for individual traffic models is caused by diverse ratio of MSs' activity/inactivity. Thus, in case of VoIP model, the MSs are in inactive state much more often than in case of Traffic Mix I/II (i.e., reporting period is more often set to t_2 instead of t_4). The Fig. 5 further demonstrates that by introduction of MRSs into the system, the size of reporting overhead can be reduced (see Scenario B in the Fig. 5). The maximal achieved reduction is obtained for Traffic Mix II, which is approximately 30% when compared to Scenario A. As already explained, the minimization of the overhead is possible due to two facts: i) the MS located at the same moving vehicle as MRS can set its reporting period to t_2 independently on the activity/inactivity and ii) the MRS is able to combine received MOB_SCN-REP messages into one message. Although, the amount of signaling overhead is increased by utilization of Scenario C, the results are still better than in case of Scenario A (especially if Traffic model II is used). The reason for the increase of signaling overhead (when compared to Scenario B) is that the MSs connected through MRS are usually connected to the BS via more hops.

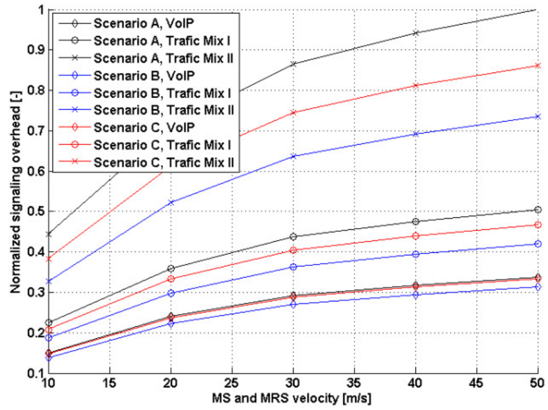

Figure 5. Signaling overhead due to reporting.

Fig. 6 illustrates how many handovers are performed per simulation run depending on MSs/MRSs velocity. The best results are achieved by Scenario B as the overall number of handovers is reduced by utilization of MRS (approximately by 50% for MSs/MRSs' velocity of 10 m/s and by 34% for MSs/MRSs' velocity of 50 m/s). The less number of handovers in comparison to Scenario A is acquired due to the fact that the MSs currently positioned at the MRS do not perform handovers. If the Scenario C is implemented, distinguishable increase of initiated handovers is observed. The reason is that in some cases the attachment via the MRS is only temporal. Nevertheless, this drawback can be mitigated by implementation of HDT. When HDT value is set to 5 s, the overhead generated by executed handovers is comparable to scenario A.

Fig. 7 presents the throughput achieved for all investigated scenarios depending on offered traffic load. In case of Scenario A, already at middle traffic load, not all data could be transmitted to the destination station. The better results are achieved for Scenario B (improvement by 9.2 %) and for Scenario C1 (improvement by 14 %).

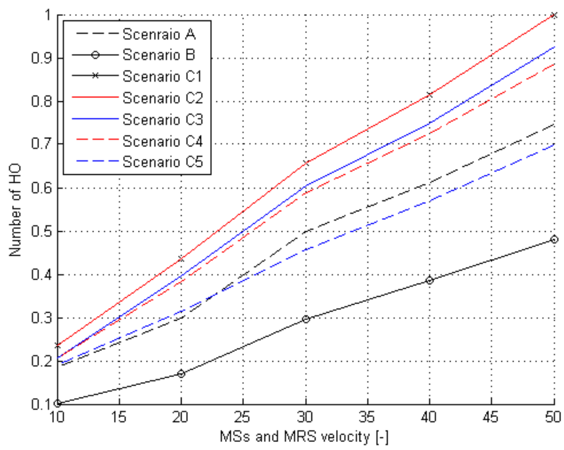

Figure 6. Number of MSs' handover per simulation run.

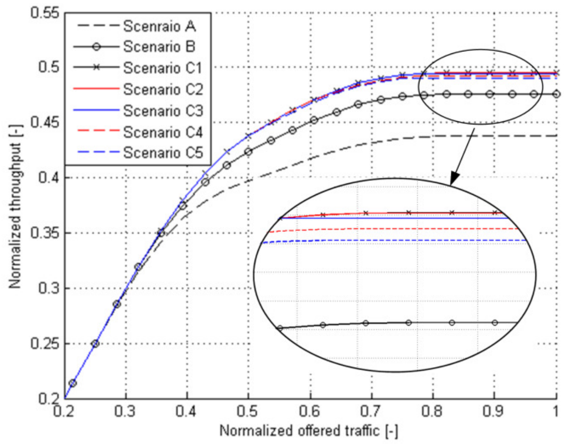

Figure 7. Normalized system throughput in dependence on offered traffic.

Decrease of system throughput by application of HDT is only marginal. From Fig. 6 and Fig. 7 can be also derived the optimal HDT value, which is 5 s as the number of performed handovers are noticeably mitigated while the system throughput is still nearly the same as case of Scenario C1.

VI. Conclusion

The paper proposed a mechanism for acquisition of CSI if MRSs are implemented into the network. In addition, detail analysis is done to estimate the amount of overhead generated by reporting messages.

The obtained simulation results indicate that system throughput can be improved since MRSs provide to its MSs better signal quality. In some cases, also the MSs not currently positioned at MRS may utilize connection offered by near MRS. In this way, the system throughput can be further enhanced. Nevertheless, this option has some drawbacks, i.e., number of performed handovers can be significantly increased as the connection through the MRS is only temporally. In order to overcome this issue, HDT is implemented. By utilization of HDT, the excessive number of HO is decreased while the system throughput is still nearly unaffected. The results also demonstrated that the signaling overhead generated by reporting of scanning information can be reduced by means of the MRS.

The disadvantage of MRSs' introduction can be seen in potential increase of interference and longer packet delays if the MSs, not currently located at the same moving vehicle as the MRS, connect to it as described in the paper. Thus, in future work we would like to addresses these issues.

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