Acquisition of Channel State Information for Routing Purposes in Relay-based WiMAX Networks

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Abstract— **The paper focuses on multi-hop routing mechanism used in relay based WiMAX networks. The proposal how to acquire channel state information (CSI) on relay and access path for de-centrally and centrally controlled relays is presented. Furthermore, on the access path the proposal distinguishes whether the user's terminals are active or inactive in order to save system resources. Based on simulation, the protocol overhead of proposed mechanism for various system configuration and parameters such as nominal channel bandwidth, number of users in the system or reporting period is evaluated. Additionally, an optimum reporting period for the system capacity maximization is determined.**

Keywords-WiMAX; CSI; routing; multihop communication

I. INTRODUCTION

The WiMAX technology is widely known as wireless networking standard that addresses interoperability across IEEE 802.16 standard-based products. So far, two standards have been already approved, the IEEE 802.16-2004 [1] intended for fixed terminals and the IEEE 802.16e [2] implementing to the former standard further features such as handover and power management modes to enable user's mobility.

Since requirements and demands to deliver high data rate are one of the current tendencies, existing technologies are trying very hard to satisfy these trends. This is the main motivation why a new WiMAX working group, entitled as IEEE 802.16j [3], was established in 2006. The IEEE 802.16j version introduces into the WiMAX system Relay stations (RSs) that have two main purposes: i) to enhance system capacity and ii) to increase network coverage.

Two concepts of RSs integration into IEEE 802.16 standard are presented in [4]. The first concept follows a centralized approach, where the Base station (BS) has full control over the relay-enhanced cell and a RS could be very simple. The second concept follows a semi-distributed approach, where a RS coordinates the associated MSs (Mobile Station) itself. In the second case, the MAC protocol complexity of RS is comparable to BS one.

In most cases, multiple RSs and BS will be within the transmission range of one another and therefore potentially communicating among themselves. Consequently, multiple routes between the BS and MS could be established. Hence, the introduction of routing techniques which will allow a BS to decide which route or routes can provide the best system performance is envisaged. The best route is chosen according to a certain metric, e.g. end-to-end throughput, delay or network congestion. To reach the maximum end-to-end throughput, the knowledge of route's CSI (Channel State Information) is required. Even though the IEEE 802.16j draft document specifies routing management for multi-hop communication, it does not describe how to acquire CSI on individual hops between the BS and MS. In [5] is proposed a signaling mechanism for efficient routing intended for IEEE 802.16j standard. Nevertheless, in the proposal the best point of attachment is decided immediately after the network entry procedure and no potential changes during MS's operation are discussed. Since MSs are supposed to be in most of the cases moving, the optimum route may change considerably during the session as well. To remedy that flaw, we propose a new mechanism for acquiring of CSI on the BS-MS path which also contemplates both the MS's mobility and its appropriate reporting periods depending on MS activity/inactivity.

The rest of paper is organized as follows. The second section gives a brief insight into CSI acquisition according to the IEEE 802.16e standard. The next section describes a proposal of CSI acquisition between the BS and MS. Additionally, proactive and reactive approaches are introduced. Section IV covers the system level simulator and basic assumptions considered during simulation are depicted. The results of simulation are shown in Section V. The last section sums up the obtained results and presents our conclusions and future plans.

II. ACQUISITION OF CSI ACCORDING TO IEEE 802.16E

Several mechanisms how to obtain CSI between the BS and MS are already defined in IEEE 802.16 standards. The most common one uses short MAC management messages called Measurement Report Request (REP-REQ) and Measurement Report Response (REP-RSP). These messages are exchanged between the BS and MS via basic CID (Connection Identifier) that is created during the initial network entry procedure (see more detail in [1] or [2]). Whenever the BS requests the CSI information (e.g. in order to adjust transmission power or to change burst profile), the REP-REQ message is sent to the MS. The MS reacts by sending the REP-RSP message containing CINR (Carrier to Interference and Noise Ratio) and/or RSSI (Receive Signal Strength Indicator) of radio channel.

Another mechanism how the BS can obtain CSI is to use a fast feedback channel (CQICH) in the uplink direction. This mechanism is applicable only on a physical layer using OFDMA mode. The CQICH channel allows MS to send information concerning CSI in fast and efficient manner.

The third option how to acquire CSI between the MS and BS is to send CINR embedded in the bandwidth request message.

The last mechanism, specified by the standard, is based on using the MOB_SCN-REP MAC management message which contains information obtained by scanning process. Time allocated for scanning process and reporting period is negotiated between the MS and BS by exchanging of MOB_SCN-REQ and MOB_SCN-RSP messages. During the scanning procedure, the MS searches for stations suitable for handover. The scanning of neighborhood is done in the scanning intervals that interleave the normal operation of MS. The results of scanning procedure are reported back to the BS. Two types of reporting are specified: a) event triggered reporting and b) periodic reporting. In the event triggered reporting case, the MS sends the reports after each measurement of channel parameters (CINR, RSSI, Relative delay and Round Trip Delay (RTD)). In the periodic reporting case, the reports are sent periodically. The spacing of individual reports is indicated by number of frames (between 1 and 255).

The main disadvantage of first three mechanisms is that CSI is obtained only between the MS and one BS. On the other hand, during the scheduled scanning procedure (the last option), the MS obtains information from all its neighbors that can be potentially used for attachment of this particular MS into the network.

III. CSI ACQUISITION IN FIXED RELAYS SCENARIOS

So far, we have considered that between the BS and the MS is a direct connection (one hop). If RSs are incorporated into the system more than one hop may be needed for a delivering of data. According to reference [3], the path between the BS and MS may be divided into two segments which can be handled separately; i) a relay path and ii) an access path (see Fig. 1). For both, relay and access path, channel state information (CSI) has to be acquired in order to decide which routing path has the best characteristics. To implement proposed method into existing WiMAX network is quite simple since only minor modifications in MAC layer are necessary. Consequently, no additional hardware modification has to be made and the new features can be provided by upgrading the firmware of equipments.

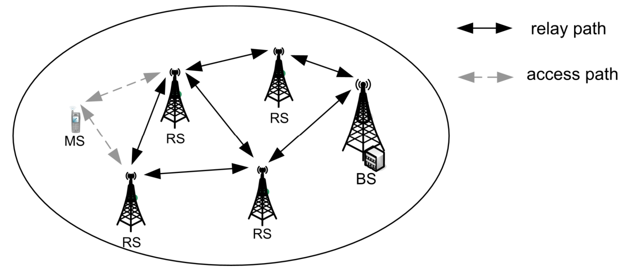

Figure 1. The relay and access paths between the MS and the BS

A. *Relay path*

Since RSs are assumed to be fixed, acquisition of CSI on the relay path (respectively the best point of attachment) may be obtained during an initial network entry procedure. During scanning process, a new RS performs measurement of signals received by its neighbors and obtains DL CINR (or DL RSSI). If only one neighbor is found, the RS proceeds the standard initial network entry procedure [1]. Otherwise, the RS performs ranging with a station from which the received signal has the best quality (see Fig.2).

In the next step, a searching of the best attachment point to the network must be initialized. Via the basic CID (created during ranging procedure), the Path Selection request message (PS-REQ) [6] is sent to the BS by new RS. This message informs BS about the channel quality between a new RS and its neighbors obtained by the scanning process. The BS decides to which station the new RS should attach and generates the PS-RSP message which informs the RS about its decision. The PS-RSP message also includes information about a recommended station that can be used to reach the BS.

If we assume that a new RS detects several RSs belonging to different BSs, the situation will be slightly different. This scenario is illustrated in Fig. 3 where the RS entering into the network (labeled as “new RS”) receives signal from the RS1, RS2 and BS2. Since the RS2 signal is received with the best quality, the new RS performs the ranging procedure with the RS2. Afterwards, the PS-REQ message is sent to the BS2 by new RS. By analyzing the PS-REQ message, the BS2 discovers that one neighbor station (namely the RS1) belongs to the BS1. In order to get CSI

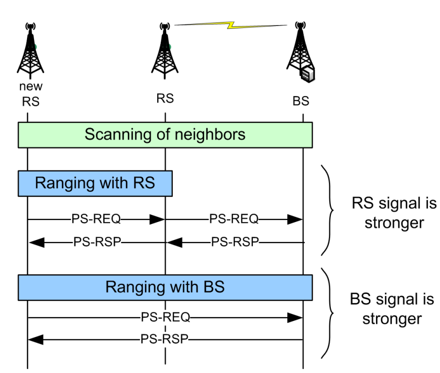

Figure 2. CSI acquisition on the relay path in single-cell scenario

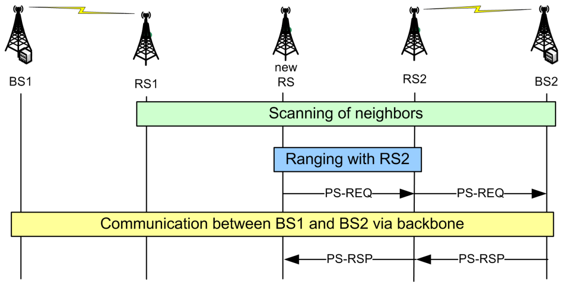

Figure 3. CSI acquisition on the relay path in multi-cell scenario

between the BS1 and the new RS, the BS2 initiates communication via backbone. When the point of attachment is chosen, the PS-RSP message is sent to the new RS.

During the RS normal operation, the BS may get new info concerning CSI by means of the REP-REQ/RSP messages or by means of fast channel feedback. Anyway, as the RSs are deployed at fixed locations, variation of channel conditions is supposed to be minimal.

B. *Access path*

In comparison with the relay path, the radio channel quality on the access path may vary in time due to the MS mobility. The period of scanning intervals allocated for individual users are handled separately for every one of them and are derived from the following parameters: i) the velocity of a given user (speed of network topology changes), and ii) activity/inactivity of the MS (receiving/transmitting data). The reporting periods are directly proportional to the MS velocity. The user's velocity may be simply derived from MOB_SCN-REP message, i.e. the magnitude of CINR (or RSSI) changes between individual reporting periods. Besides the speed of users, another factor should be pondered; i.e. traffic generated to or from given MS. If we employ a terminology used in ad-hoc routing protocols, the hybrid principle method [7] is considered. A proactive approach [7] may be used when no data are sent at all, i.e. the MS is in inactive state. A reactive approach [7] may be utilized when the MS starts send or receive data; the MS is in active state.

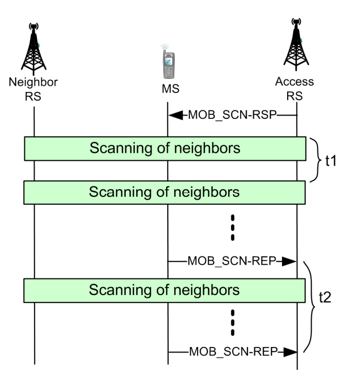

Figure 5. Scanning and reporting periods when no data are transmitted (de-centrally controlled RS)

1) *Proactive approach*

In this scenario, the MS scans its neighbors with a period t1 and reports its measurements within a period t2, where t2 should be integral multiple of t1 (see Fig. 4 and Fig. 5). Both, the scanning and reporting periods (given in the MOB_SCN-RSP), are exclusively derived from the speed of the MS and occur relatively infrequently in order to save valuable radio resources. Nevertheless, the MOB_SCN-REP may be send by MS in unsolicited fashion anytime when DL CINR of the radio channel between the MS and the access RS is below a certain value for a certain amount of time. This principle guarantees that a handover can be made in advance and CINR between the MS and access RS does not drop below a certain threshold value.

Additionally, since no data are sent, a complex calculation of the optimal route between the MS and BS is not necessary. Moreover, the BS doesn't have to acquire CSI of routes between the MS and BS via the backbone network. Consequently, the best route is chosen in the suboptimal manner where only the last hop is considered. Thus, de-centrally controlled RS may schedule the scanning and reporting period only according MS velocity (see Fig. 4) without intervention of the BS. On the other hand, when centrally controlled RSs are used, the MOB_SCN-RSP message has to be sent by the BS to inform the MS about allocated scanning intervals. The MS performs scanning with all its neighbors and reports the results to its access RS which further relays this message towards the BS (see Fig. 5).

2) *Reactive approach*

Generally, the scanning and the reporting period are much shorter in comparison with MS's inactive state in order to route data through most appropriate path. More than that, the best route has to be chosen according to the best end-to-end quality. Therefore, a decision in suboptimal manner is no longer suitable as in case of the proactive approach.

In case of using centrally controlled RSs, the BS learns about MS's transition from the inactive to the active state either through BW request which originates at the side of MS or when the BS has some data that are designated to this MS (see Fig. 6). Consequently, the BS transmits another MOB_SCN-RSP message in order to schedule new scanning

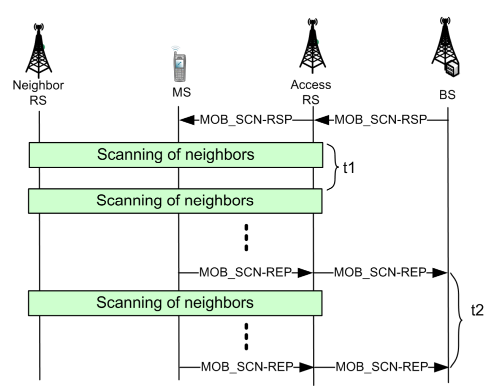

Figure 4. Scanning and reporting periods when no data are transmitted (centrally controlled RS)

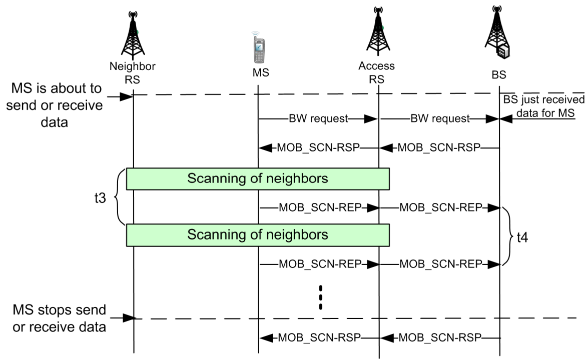

Figure 6. Scanning and reporting periods when data are transmitted (centrally controlled RS)

and reporting intervals. In other words, scanning shall take place every t3 intervals instead of t1 and the measurement report should be send to the BS every t4 intervals instead of t2 intervals (t3 and t4 are much shorter than t1 and t2).

If the MS sends the MOB_SCN-REP after each scanning procedure, as indicated in fig. 6, the length of interval t3 and t4 is the same. After the BS receives a report where one or more neighbor stations belong to other BS(s), the BS may request information on that path via backbone network. Since relays are assumed to be fixed the BS may already know the CSI between another BS and its RSs e.g. by means of the network entry procedure. When all scheduled data related to the given MS are transferred, the BS immediately send the MOB_SCN-RSP message with new allocated scanning and reporting intervals (in the same way as it is described in the previous section) in order to save system resources.

If de-centralized RSs are implemented (see Fig. 7), the situation is a slightly more complex, since the BS doesn't know when a MS is about to send or receive data (see [4]). The BS considers de-centrally controlled RS as another subscriber station and has no knowledge regarding stations that are attached to this RS. In a situation when the MS is requesting a bandwidth, the RS processes the demand. If RS itself is able to carry MS's data, BW request is not send any farther to the BS as in the centralized RS scenario.

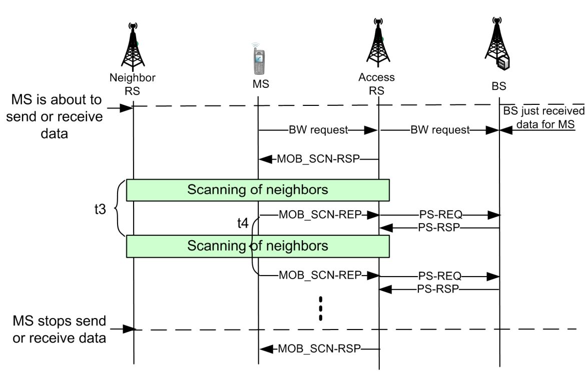

Figure 7. Scanning and reporting periods when data are transmitted (de-centrally controlled RS)

Otherwise, the RS sends own BW request to its superior station (either the BS or other RS). In the next step, the RS constructs the MOB_SCN-RSP of its own with new schedule of scanning and reporting periods.

Nevertheless, the RS has no means how to acquire quality of other possible routes (e.g. CSI between the MS-Neighbor_RS-BS or MS-Neighbor_RS-other_BS) and some assistance from the BS is necessary. One solution is to send the PS-REQ message by the RS to the BS in the same manner as it is described in section 3.1. Subsequently, the BS calculates metrics of all possible routes and the result is sent back to the RS in the PS-RSP message. This way, the access RS may find out if handover should be initiated or not.

For the purposes of bandwidth saving, the PS-REQ message may be send, e.g. every n*t4 interval. Especially if a fixed scenario is assumed, CSI between the BS-RS and the RS-RS is quite stable and unvarying in time. As a result, the RS learns about these links at the beginning of scanning process. Thus, the RS is able to calculate best metric without the guidance of BS for most of the time. After the whole amount of data intended for the MS are transferred, the access RS indicates to the MS to return to the proactive state by sending the MOB_SCN-RSP message.

Very important aspects which have to be considered especially for active MS's states are i) periodicity of MS's scanning intervals and ii) periodicity of MSs reporting period. On one side, the more frequent reporting is used, the more precise information about the network topology the BS has and the better management of radio resources can be done. On the other side, the overhead caused by MAC management messages may be significant. Thus, tradeoff between acquisitions of up to date CSI knowledge and signaling overhead is to necessary analyze.

IV. SIMULATION SCENARIO

The simulations are done in MATLAB environment. The parameters setting is given in Tab 1. The analyzed scenario assumes the worst case where all users are in the active state and centrally controlled RSs are used. The simulation model is composed of one BS and eight fixed RSs. A deployment of individual stations is illustrated in Fig. 8. Additionally, individual mutual connections (i.e. possible routes to/from the BS) and distances are depicted. The maximum distance between the RS and BS is restricted on two hops. The RSs positions are chosen so that all MSs are always in a transmission range at least one station (the BS or RS).

In order to manage individual MS movement, a mobility model is implemented. At the beginning of simulation, an initial position of each MS is randomly determined in such a manner, that the MS has to be located within defined range, i.e. between 0 to 800 m from the BS. Additionally, a velocity and a random movement direction are determined for all individual MSs in the system. The mobile terminals are moving along straight line until the distance from the BS is equal or larger than defined BS 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.

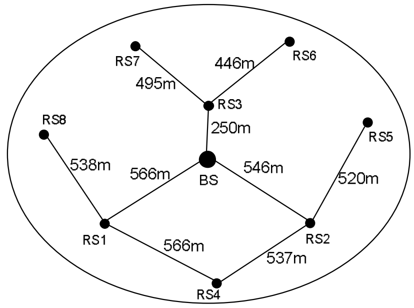

Figure 9. The BS and RSs deployment

Two path loss models taken from [8] are implemented. The first one is suitable for LOS communication and describes radio channel behavior between the BS-RS and the RS-RS (in [8] denoted as "type D"). The second one is assigned for NLOS communication between the BS-MS and the RS-MS (in [8] denoted as "type E").

The first step, amount of overhead introduced by an acquisition of CSI between the BS and MSs is analyzed. The protocol overhead is proportional to: i) the size of the MOB_SCN-REP message (more MS's neighbors results in larger reporting message), ii) number of active MSs in the system, iii) number of hops between individual MSs and the BS (how many times the MOB_SCN-REP has to be relayed to reach the BS) and iv) system configuration (e.g. reporting period, nominal channel bandwidth, OFDM parameters, etc.).

Furthermore, the optimal reporting period for overall throughput maximization is determined. To evaluate the maximal throughput, a full queue traffic model is implemented [9]. The throughput evaluated in the paper represents a rough system WiMAX capacity obtained at the MAC level. The rough capacity represents capacity when the overhead introduced by higher layer protocols (e.g. network, transport, etc.) is not considered. Nevertheless, the impact of such an overhead is the same for all compared scenarios so the final results are not influenced by this assumption.

The path between the BS and MS is determined according to the minimum Radio Resource Cost (RRC) metric (more detail may be found in [10]). The RRC is measured by number of OFDM symbols needed for transmission of certain amount of data burst (e.g. 1000 bits). To decide which point of attachment is the best for the system performance, the RRC compares all available routes

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Frequency band (GHz)	3.5
Channel bandwidth (MHz)	3.5-20
Number of MS	1-50
MS's velocity [m/s]	10-50
Frame duration (ms)	10
Number of OFDM subcarriers	256
Number of data subcarriers	192
BS transmit power P_t (dBm)/height(m)	30/30
RS transmit power P_t (dBm)/height(m)	30/30
MS transmit power P_t (dBm)/height(m)	30/2
Noise (dBm)	-100.97

from (to) the BS and determines how much system resources have to be allocated.

V. SIMULATIONS RESULTS

In order to evaluate the protocol overhead, the simulator captures during scheduled reporting period current overhead generated by all active users (up to 50). The length of simulation corresponds to 10 minutes of real time where all MSs are moving with speed of 20 m/s. The protocol overhead depicted in Fig. 9 and Fig. 10 represents a mean value generated during the whole simulation time.

Fig. 9 shows how the protocol overhead is influenced by various system configurations; i.e. by radio channel bandwidth and periodicity of reporting period. For a narrower channel more radio resources are expended for CSI acquisition. The reason of that is that by using of narrow channels (e.g. 1.75 or 3.5 MHz), OFDM symbol duration is longer than in a wider channel. As a consequence, the number of symbols per frame is necessarily smaller. Thus, more percentage of OFDM symbols is used for overhead. If we consider nominal channel bandwidth of 1.75 MHz and reporting period shorter than 0.05 s, the amount of protocol overhead is more than 20 %. On the other hand, for the channel size of 20 MHz the quantity of protocol overhead is insignificant for all reporting periods longer than 0.05 s (less than 2 %).

Fig. 10 shows amount of protocol overhead (in kb/s) versus the number of MSs and the reporting period. Several scenarios with different reporting period are considered. If reporting periods occur every frame (0.01 s), the overall overhead is quite significant. This statement is especially true for a lot of active users (for 50 users is more than 600 kb/s). Anyway, when the reporting period takes place, e.g. every ten frames (0.1 s), the overhead incurred by the protocol is almost negligible. Thus, the more considerable matter is how the reporting period affects the overall system performance.

Fig. 11 addresses the question how often the reporting period should be scheduled in order to get the maximal system capacity while the overhead introduced by the signaling protocol is minimal. Since the major factor here is the speed of topology changes, the impact of different user's velocity (from 10 to 50 m/s) is investigated. The overall

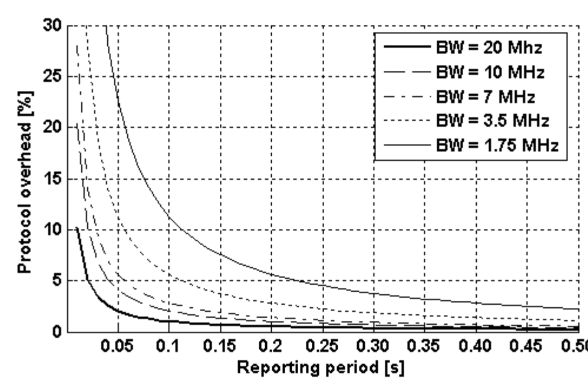

Figure 8. Protocol overhead in dependence on system bandwidth and reporting period (50 active users is considered)

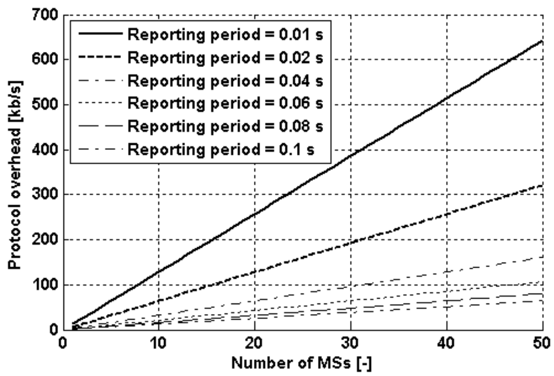

Figure 10. Protocol overhead in dependence on MS's number and reporting period

throughput is calculated in the same way as the protocol overhead; i.e. the length of simulation is 10 minutes of real time and the resulting bit rates are averaged for every reporting period and MS's velocity. As expected, with growing users speed, the optimal reporting periods are shorter. In other words, if the MS is moving relatively slowly, more preferable solution is to increase the reporting period to save radio resources. When all MSs are moving with speed of 10 m/s, it is optimal to send the MOB_SCN-REP message approximately every 0.75 s (i.e. every 75th frame). However, if MS's speed is high, 50 m/s, the ideal scanning period is 0.32 s (every 32nd frame). In the case that these conditions are not satisfied, decrease of system capacity can be observed.

VI. Conclusion and Future Plans

This paper proposes a new mechanism for acquirement of CSI in WiMAX networks enhanced by fixed relay stations. Both, the relay and access path, are taken into consideration. To that end, the amount of overhead introduced by signaling protocol is evaluated for various system configurations. Results show that the overall

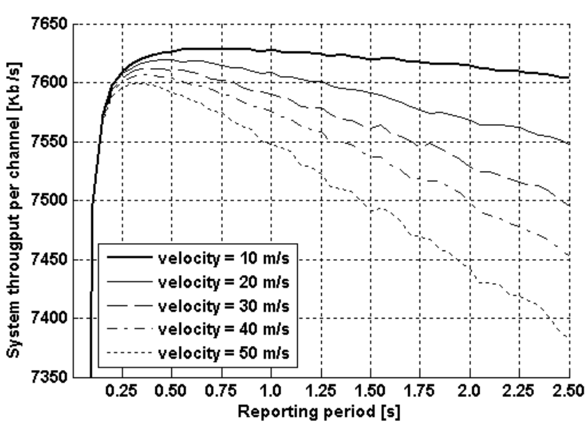

Figure 11. System throughput in dependence on MS's velocity and reporting period (50 active users is considered)

overhead significantly depends on nominal channel bandwidth, speed of active users and number of users. Although, the worst case scenario is considered, protocol overhead may be minimized for majority of cases. This can be achieved by prolonging of reporting periods to reasonable values (i.e. hundreds of ms). Additionally, the optimum periodicity of reporting period is derived in dependence on the number of users. The ideal reporting period for users with speed of 10 m/s is approximately 0.75 s while ideal scanning period of 0.32 s should be applied to users with speed of 50 m/s. Nevertheless, the periodicity of optimum scanning period is directly proportional to the coverage area of the BSs and RSs (in other words, to the frequency of handover process initialization).

Since all proposed modification are only at MAC layer level, the protocol alone may be implemented simply by updating of equipments firmware and no further hardware adjustment are not necessary.

Other important issue in multi-hop communication, which has not been taken into account in this paper, is how to protect relay stations against overloading. For this purpose, it is necessary to provide routing according to RS's load that is our future work.

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