Optimization of Network Entry Procedure in Relay Based WiMAX Networks

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Abstract - The paper focuses on a network entry procedure in the IEEE 802.16 standards. The procedure in PMP mode is briefly described and further contemplates how the original procedure is modified when introducing relay stations into the system. On the basis of simulation, the paper proposes an enhancement to the original association procedure in relay scenarios by adding a new phase called Path selection. Thanks to this feature, the overall system performance may be increased.

1. INTRODUCTION

The WiMAX technology is a worldwide 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 scenarios and the IEEE 802.16e [2] implementing to the former standard some mobility features such as handover and power management modes.

Since requirements and demands to deliver high data transmission rates are one of actual tendencies, existing technologies try to satisfy these trends. This is the main motivation why a new WiMAX working group, entitled as IEEE 802.16j, was established in 2006. The IEEE 802.16j [3] version introduces into the system Relay stations (RSs) that have two main purposes: i) to enhance system capacity and ii) to increase network coverage (see fig. 1).

The RS equipments represent simplified Base Stations (BSs). They provide media access management in its area and data transfer between BS (or other relays) and Subscriber Stations (SSs). In this way, there can be significantly improved network efficiency and reduced costs of its establishment. How to integrate the RSs into the IEEE 802.16 network is shown in [4]

When a new SS associates to the WiMAX network, several steps have to be accomplished during the initial process. Although, the IEEE 802.16-2004 and 802.16e define the network entry procedure point to multipoint (PMP) network topology (mandatory) and mesh network topology (optional), association in relay based network has to be modified due to implementation of RSs.

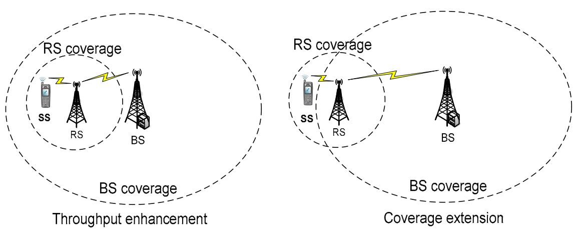

Fig. 1. The fashion of RS utilization in WiMAX networks

The next section briefly describes the network entry procedure for PMP mode (the optional mesh topology is not taken into consideration). Section III depicts the enhancement to the original network entry procedure. Section IV describes the simulation model and discuses obtain results. The last section gives our conclusions.

2. ASSOCIATION PROCEDURE IN WIMAX STANDARDS

The network entry procedure can be divided into several phases. In every phase, specific MAC management messages are exchanged between the BS and SS. For the reason of simplicity, Fig 2 shows only mandatory network association steps.

At the beginning of procedure, the SS scans individual downlink (DL) channels searching for the DL-MAP and DCD messages broadcasted by the BS. Via these messages, the SS gets synchronize with the BS and obtains DL parameters. When successfully synchronized, the SS waits for the UL-MAP and UCD messages to obtain UL parameters.

Through the UL-MAP, the SS discovers initial ranging slots in which the RNG-REQ message is supposed to be sent to initiate the process of ranging. Within the ranging process, the SS acquires transmission parameters such as time offset, transmitted power level along with basic and primary management connection identifiers (CID).

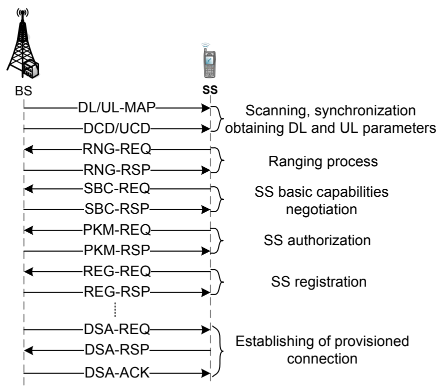

Fig. 2. Message exchange between the BS and SS during network entry procedure for PMP mode (based on [1])

Immediately after the ranging process, the BS and SS exchange basic capabilities parameters supported by both of them. The next phase of initialization is intended for SS authorization and keys exchange (authorization and traffic encryption keys).

After the authorization phase is completed, the SS must register itself into the network. That step is accomplished by the SS registration. If the managed SS provides IP services, a secondary management CID is assigned to the SS and three optional phases of network entry procedure are performed in the next step (these phases are more detail in [1]). The whole process of association is terminated by establishing the connections.

3. PROPOSED CHANGES IN ASSOCIATION PROCEDURE FOR RELAY BASED NETWORKS

The association procedure for a SS in the relay based network is partially different. To satisfy backward compatibility with legacy standards, a RS must behave to the SS exactly the same way as a regular BS. Since the SS does not distinguish the BS and RS, the SS tries to associate to the station with better signal. However, this decision doesn't have to be the most appropriate with regard to the system throughput.

If the signal from the RS is stronger than that one from the BS, the SS initiates network entry procedure with the RS. Nevertheless, the path to the BS through the RS involves two (or more) hops and the overall capacity can be lower in comparison with the direct link.

On the other hand, if the BS signal is stronger than the RS one, the SS associates to the BS. This network attachment is optimum for a DL data transmission and not necessarily for an UL data transmission. An efficient way how to prevent these drawbacks is to implement a mechanism that determines stations to which a SS should associate (or re-associate).

Two types of association procedure can be distinguished: i) the SS receives signal only from one station or ii) the SS receives signal from multiple stations. In the first type of scenario, the whole network entry procedure is the same as the one described in section II. The SS is either in the range of BS or in the range of RS. Thus, there is no need to decide which of the connections is more suitable. In the latter case, case ii, the association process has to be enhanced by the path selection step.

3.1 BS Signal is better than the RS one

The SS performs the initial ranging procedure with the BS (see fig. 3). During this process, there are created basic and primary management connections.

The next step (the new one in the SS association) is the searching for the best attachment point to the network. Via the basic management connection the Path Selection request message (PS-REQ) is sent to BS. This message informs BS about the channel quality between the SS-RS and SS-BS (information is obtained from SS measurements). Since it is assumed that the channel quality between the RS and BS is known, the BS may decide which path is more suitable from the point of view of system performance. The BS answers to the RS with PS-RSP message. There are two scenarios that can occur:

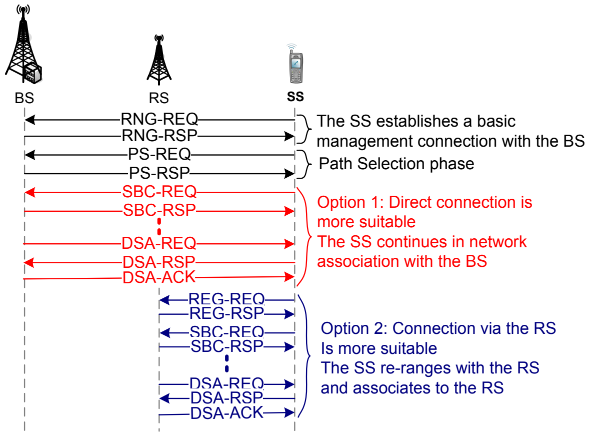

Fig. 3. Proposed message exchange during the association process when BS signal is the better

i) the direct connection is more beneficial (in fig 3 labeled as option 1) or ii) the connection along the intermediate RS is more suitable (in fig 3 labeled as option 2). In both cases, the BS transmit PS-RSP only to the SS (RS needn't to be informed about BS decision).

If the BS decides that the SS shall directly associate with the BS, the rest of the network entry procedure matches the original procedure. In the second case, the SS has to perform the ranging with RS in order to synchronize with the station and to establish the basic and primary management connections. After the ranging procedure, the individual association steps follow.

3.2 RS Signal is better than the BS one

In case, the RS signal is stronger, the SS starts the ranging process with RS. Subsequently, the SS sends PS-REQ message via the basic management connection created during the initial ranging process. In comparison with the previous case, the RS forwards this message to BS (the RS has not the capability to make the decision). If the attachment to the BS is more suitable (in fig 4 labeled as option 1), the SS performs the initial ranging process with the BS. After that, the SS goes through the same steps as described in the previous scenario. If the attachment to the RS is better in terms of system end-to-end throughput, the SS continues in the association process with RS (in fig 4 labeled as option 2).

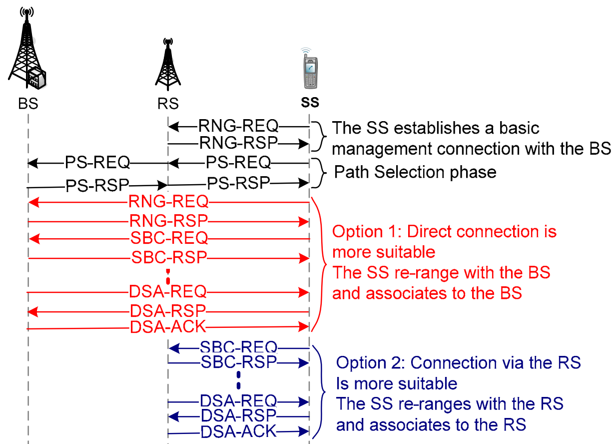

Fig. 4. Proposed message exchange during the association process when RS signal is the better

4. SIMULATIONS

4.1 Model of simulations

The aim of simulation is to determine to which station (the BS or RS) a SS should associate to maximize the system throughput. The simulation model consists of one BS and 6 RSs (deployment of BS and RS is shown in fig. 7). There is estimate every possible location of the SS in the BS cell in the following successive steps.

Firstly, the SNR received by the SS is evaluated using the following expression,

$$SNR = P_t - PL - Noise \qquad (1)$$

where P_t is the transmitted signal strength at the side of a receiver and *Noise* represents either only thermal noise (see Table 1) when no interference is introduced, or it is summation of thermal noise and interferences. The *PL* term in expression (1) represents a path loss channel model applied in the simulations. The model was developed by Stanford University and the basic path loss equation with correction factors [5] is calculated as,

$$PL = A + 10\gamma \log_{10}\left(\frac{d}{d_o}\right) + X_f + X_h \qquad (2)$$

where d is the distance between the transmitter and receiver antennas in meters (d_0 = 100 m). The A parameter is defined as,

$$A = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \qquad (3)$$

where λ is wavelength. Parameter γ in expression (2) is estimated on the assumption that urban environment is considered. Finally X_k and X_f are correction factors the CPE antenna height and the operating frequency (more detail about γ, X_k and X_f can be found in [5])

After calculating the SNR, there is found out which of path, direct or via the RS, is more suitable from the point of system performance. To accomplish this phase, a metric determining radio resource cost (RRC) is implemented. The RRC can be measured either by number of OFDM symbols or by time allocated for transmission (derived from CINR). The metric is shown in figure 5.

The maximum system capacity is proportional to expression (4) for the DL case and to expression (5) for the UL case.

Parameter	Value
BS range radius (m)	2600
RS range radius (m)	1000
BS-RS distance (m)	1470
Frequency band (GHz)	5
Channel bandwidth (MHz)	20
Frame duration (ms)	20
Number of data subcarriers	192
BS transmit power P_t (dBm)/height (m)	30/30
RS transmit power P_t (dBm)/height (m)	27/25
SS transmit power P_t (dBm)/height (m)	25/2
Noise (dBm)	-100.97

Table 1. Simulation parameters

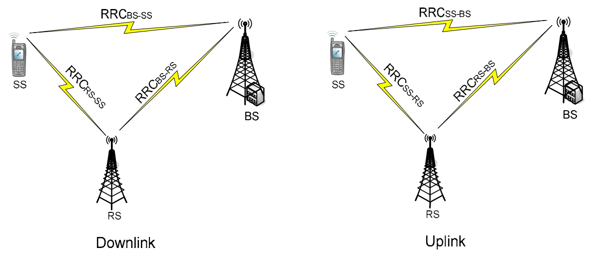

Fig. 5. The example of metric to determine optimal attachment point in DL and UL directions

$$DLMC \approx \min\{RRC_{BS-SS}, RRC_{BS-RS} + RRC_{RS-SS}\} \qquad (4)$$

$$ULMC \approx \min\{RRC_{SS-BS}, RRC_{SS-RS} + RRC_{RS-BS}\} \qquad (5)$$

where RRC_{BS-SS}, RRC_{BS-RS} and RRC_{RS-SS} correspond to RRC between individual stations. If the RRC_{BS-SS} is smaller than summation of RRC_{BS-RS} and RRC_{RS-SS}, the SS associates to the BS since the BS-SS connection is more favorable. Otherwise, the SS associates to the RS in order to maximize the system performance.

To perform this evaluation, the BS needs to know RRC_{BS-RS}, RRC_{RS-SS} and finally RRC_{BS-SS}. It is assumed that these values shall be known at the BS and can be derived from the applied modulation and coding rate.

However, even this solution may not be the best in every situation. If we assume that more then one RS is transmitting at once (see figure 6), even this metric is not suitable to calculate best end-to-end throughput since the reuse of radio resources gives an advantage to scenarios with RSs over that with no relay. For these cases should be applied the following expression:

$$DLMC \approx \min\{RRC_{BS-SS1} + RRC_{BS-SS2}, RRC_{BS-RS1} + RRC_{BS-RS2} + \max\{RRC_{RS-SSx}\}\} \qquad (6)$$

The last term represents the number of OFDM symbols used in the 2nd hop transmission. Since the quantity of SSs and their demands for every RS may differ, the $RRC_{RSx-SSx}$ shall differ for each RS. Consequently, the estimation of the largest $RRC_{RSx-SSx}$ has to be made.

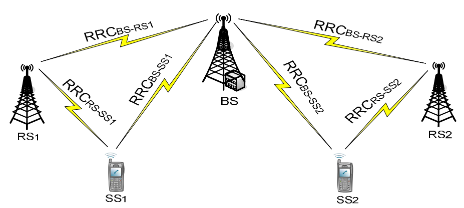

Fig. 6. The example of metric to determine optimal attachment point in DL while reuse of radio resources is exploited

4.2 Simulation results

Within simulations, several scenarios are considered; i) association according to received SNR, ii) association according to performance in DL or UL and finally iii) association according to performance when reusing RSs radio resources.

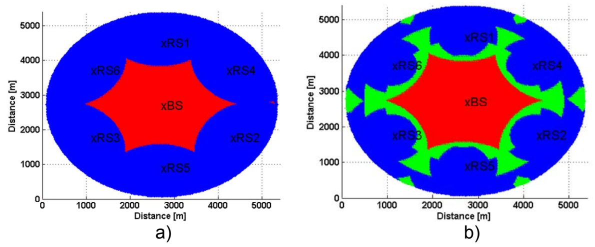

Fig. 7. Association according to the best performance in DL

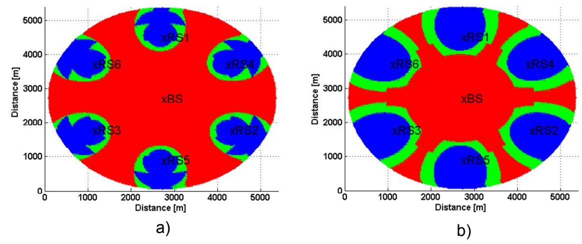

Fig. 9. Association when reuse of RSs resources is enabled

Fig. 7a depicts a case where a SS associates according to SNR received by nearby stations. This scenario corresponds to the standard network entry procedure. If the SS is situated in the red area (24 % of BS overall coverage), the SS associates to the BS - it is assumed that this alternative is better. If the SS is located in the blue area, the SS initiates the association procedure with one of the RSs.

Fig. 7b shows situation where the expression (4) is employed. The green area (18 % of BS overall coverage) represents events where the association according to the standard procedure decreases the system performance as the direct connection to BS is more preferable.

However, the decision is only made with respect to DL direction. In case of UL direction, the situation is quite different (see fig. 8a). Consequently, the decision based on the original network procedure provides better results compared to the first.

Fig. 8b compares the system performance for the following three cases; i) association according SNR, ii) association according to maximum DL performance and iii) DL and UL associations are done via different radio links. The simulation is provided for SS positioned as indicated in fig 8a. For the sake of simplicity, the individual bit rates are derived from the channel capacity (MAC overhead is neglected). Anyhow, this simplification doesn't affects the results as the conditions are the same for all scenarios.

On the basis of first two scenarios can be seen that tradeoff has to be done to maximize the system performance depending on the amount of DL and UL directions. For example, in case of broadcasted service is better to make the decision with respect to DL conditions. From fig. 8b, it can be observed that the third scenario offers the best results. On the other hand, the system complexity is higher.

So far, the estimations were based on a fact that a reuse of RS resources is not taken into account. If the reuse of scarce radio resources starts to be considered, the results

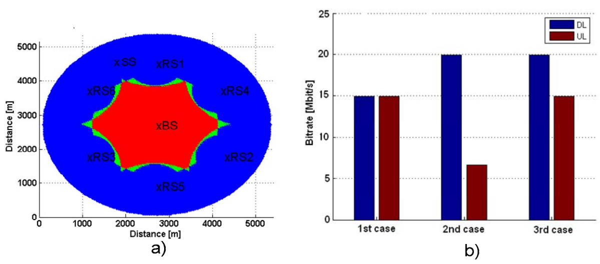

Fig. 8. Association according to the best performance in UL

are quite different as it shown by fig. 9. Fig 9a, respectively 9b, illustrates a case when the simulations consider expressions (4) and (5), respectively expression (6). In the first case, the SS associate directly to the BS in 74.5 % (red area-64.5% plus green area-11%). Nevertheless, the decision to associate to the BS degrades the system performance as the used metric doesn't take into account the reuse of radio resources. In the second case (fig. 9b), the mechanism of reuse of radio resources is taken into account. In this scenario, 58% events (blue area 33.5 % and 22.5% green area) connect via the RSs.

5. CONCLUSION

The paper focuses on a network entry procedure in WiMAX systems and its enhancement in relay based networks. It is shown that by the new algorithm, the overall system performance can be increased.

To implement these modifications into existing SS equipments only require changes at MAC layer level. Thus, no additional hardware modification has to be made and the new feature can be provided by upgrading the firmware of equipments.

ACKNOWLEDGMENT

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