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LOAD-AWARE BASED INDEPENDENT INFORMATION SERVICES FOR HETEROGENEOUS HANDOVER

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Abstract. *The heterogeneity of multiple radio access technologies (RATs) is a key characteristic for next generation mobile network (NGMN) as there is no single existing legacy RAT that provides ubiquitous services to mobile users. Therefore, the problem for mobile services over heterogeneous networks lies in how the on-going sessions can be maintained using seamless handover when a mobile node (MN) moves across network boundaries. In this paper we propose a network-assisted terminal-controlled handover scheme by implementing the chord-based decentralized IEEE 802.21 media independent information service (MIIS) server to accelerate the process of collecting network-related information. Furthermore, we include a load-aware network capacity estimation algorithm in our network selection scheme to estimate the network capacity separately at the terminal. Simulations show that the proposed handover scheme improves the handover performance in terms of packet loss rate, throughput and handover delay. Finally, we also give a performance evaluation on the lookup delay of the proposed chord-based decentralized MIIS servers.*
Keywords: Decentralized media independent information service (MIIS), Hierarchical distributed hash tree (DHT), Vertical handover, Load-aware, Heterogeneous environments

1. **Introduction.** The quest for ubiquitous wireless access has led to the early introduction of a wide variety of new access networks and Internet-capable devices [1]. However, the substantial characteristics in nature of each network impose a great challenge to alone satisfy MN's requirements for accessing any service from anywhere at any time. The heterogeneity of multiple RATs is a key characteristic for NGMN. Therefore, the problem for mobile services over heterogeneous networks lies in how the on-going sessions can be maintained using seamless handover when a mobile node (MN) moves across network boundaries. In response to this, the IEEE 802.21 has taken initial efforts to develop a standard dealing with the issues related to the handover between networks of different technologies [2]. Its general idea is to use a media independent handover (MIH) layer between link and network layers to hide the heterogeneity of lower layers and to enable upper layer (such as mobile IP (MIP) in network layer, session initiation protocol (SIP)

in transport layer and applications) to gather available information from lower layers to enhance the performance of mobility. A lot of research activities on MIH framework have been done by academic society [3-5], which rely mostly on two MIH services: the media independent event service (MIES) and the media independent command service (MICS). These schemes take advantage of the lower-layer information, such as link detection message and link going down message and command to initiate handover process, to initiate a handover. The exploration of the third MIH service, which is the media independent information service (MIIS), is very less.

In this paper we focus on the architecture and functionalities of MIIS with a network selection scheme, and point out ways to enhance the experience of MN in handover. We propose a chord [6] based MIIS that is maintained by a set of MIIS servers to enhance the resilience, fault tolerance and scalability of the overall system simultaneously to facilitate the handover performance. Chord is one of the first distributed hash trees (DHTs). Along with the MIIS, a network-assisted terminal-controlled handover scheme is proposed as well, where an MN initiates handover according to the changes of the link state, and sends information request to the closest MIIS server while the MIIS server is responsible for network discovery. Then, the MN initiates network selection and executes a handover according to the proposed network selection algorithm described in Section 4. NS2-based simulation results show that our proposed scheme improves the handover performance in terms of packet loss rate, throughput and delay. Meanwhile, we also give an evaluation on the lookup performance.

The remainder of this paper is organized as follows. Section 2 outlines of the IEEE 802.21 standard and a literature survey on the most relevant related works. Section 3 provides a high-level description of the architecture, functionalities and the chord-based decentralized organization of the MIIS servers. Also, it describes the complete steps of the network discovery procedure adopted by the MIIS server. Followed by a network selection scheme which bases on a network capacity estimation algorithm is described in Section 4. Performance evaluation using NS2 and result analysis are presented in Section 5. Section 6 concludes this paper and discusses possible future work.

2. **Literature Review.**

2.1. **IEEE 802.21 media independent handover (MIH).**

In 2004, the IEEE 802.21 working group was formed to address the issues related to the media independent handover (MIH) standard. The main goal is to provide link layer and other network-related information to the upper layers to optimize the handover between networks of different access technologies including 3GPP and non-3GPP networks [7-9]. The general idea is to make heterogeneity of the lower layers of various access technologies transparent by introducing a new layer called the MIH (2.5) layer between the network and the link layers. Therefore, the network operation and management can be ameliorated by the communication among the MIH layers. Figure 1 depicts the MIH architecture as proposed by the IEEE 802.21. During the network discovery, network selection and handover execution, an MIH specified logical functional entity: media independent handover function (MIHF) uses service access point (SAP) to associate with link and network layers to provide synchronous and non-synchronous services including media independent event service (MIES), media independent command service (MICS) and media independent information service (MIIS).

As shown in Figure 1, MIES defines the causes of handover due to the action of the users, the state of the environment or some other network management functions of event classification, event filtering and event reporting to the upper layers. These events can

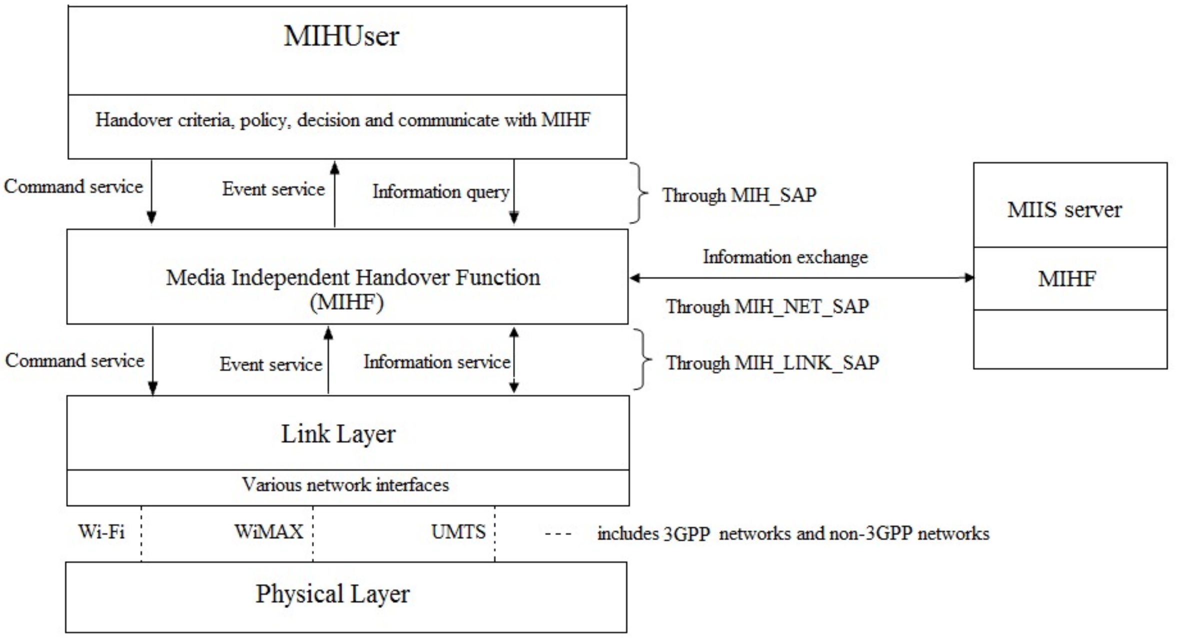

FIGURE 1. MIH general architecture

be generated by the MAC layer, the physical layer or the MIHF in the mobile device or the network. On the other hand, MICS is initiated by upper layer which sends command to the lower layers. It is divided into two categories: the MIH command and the link command. The MIH command is created by the MIH user to MIHF while the link command is sent by the MIH layer to the MAC or the physical layer. MIIS mainly deals with supplying information about the neighbor networks, such as network type, capability, points of attachment (PoAs) address, IP configuration method and security, for effective handover. In [10], authors proposed an MIES-based scheme to gather dynamic information of candidate networks for a centralized handover decision. The author compared their scheme with a query-based scheme; results show that their scheme outperform in terms of signaling overhead and information access delay. In [11], authors proposed an enhancement on MIH to address the issue related to simultaneous handover. Simultaneous handover occurs when the both communicating MNs are during handover procedure. Two new MICS primitives were defined. *MIH_Update_PoS* is used by MN to inform IP address of its PoS to correspondent node (CN) and *MIH_Update_IP* is used to report its new IP address to the PoS of the CN. In [12], authors proposed a method which uses an enhanced MIIS server to facilitate handover procedure in MIH-enabled networks. In this handover scheme, authors estimated the wireless channel conditions from the perspective of spatial and temporal at the MIIS server. Simulation results show this scheme can reduce the handover delay as the channel scanning procedures can be skipped. The actual design and implement method of the MIIS server are not specified by the MIH standard. Hence, in our work, we fill out this gap by proposing the architecture and functionalities of the MIIS server.

2.2. **Extensions and amendments on MIH facilities in handover management.** The IEEE 802.21 draft specification [13] defines a media independent handover function (MIHF) to improve the handover performance in the heterogeneous environment. The ultimate purpose of the MIH standard is to offer the transparent handover that is independent in media by offering intellectual information of lower layer among various networks. A proposal to add the QoS layer on top of the MIH layer specified by IEEE 802.21 MIH has been proposed in [14]. It uses an intelligent decision module for better interface selection considering the available information provided by the QoS parameters. A QoS-aware handover initiation algorithm was proposed in [15], in which the QoS performance is based on the packet loss, and a link level simulation was given. This work is a bit similar to ours, but our proposed scheme considers the QoS in the process of network selection and meanwhile our proposed work gives a more detailed evaluation on the system level performance. In [16], authors introduced an access network discovery and selection scheme which was used between 3GPP and non-3GPP networks. In [17], a load-balance based algorithm in LTE was proposed, and also an extensive simulation was given and from the result it can be seen that the proposed method presented a good performance in terms of call blocking rate, total utility and cell-edge throughput. The author in [18] gave an analysis on the capacity of WCDMA network, which is similar to our research motivation. However, our proposed method took QoS and network load balancing into consideration. Authors in [19] introduced a method in which MIH framework was integrated into IP multi-media subsystem (IMS) to optimize the quality of end-to-end service. A hierarchical MIIS infrastructure is developed to exchange information such as QoS and cost-related parameters, but the details of MIIS infrastructure and specifications were not given.

Looking at these previous works, which mostly rely on the IEEE 802.21 MIES and MICS services, MIIS seldom is taken into consideration, even if some works tried to investigate the MIIS, it covers only limited aspects such as the location of MIIS server and/or the message exchange between MIIS server and MN. Few of usage details, architecture and functionalities have been mentioned. Our work presents the detailed information on architecture and functionalities of the MIIS server and a decentralized MIIS framework is described. Meanwhile, based on the proposed MIIS server, we also propose a network capacity estimation algorithm to select the best target network.

3. Architecture and Functionalities Design of the Proposed MIIS.

3.1. The architecture of proposed MIIS server.

The basic structure of MIIS is not completely defined in the IEEE 802.21 standard. Generally, the MIIS should have the following features:

i. The MIIS server, through MIH network service assess point, communicates with the MIHF in the local node to interact with the MIH-enabled nodes.
ii. The MIIS server is capable of collecting, maintaining, updating and cleaning network information included in the database.
iii. If the handover scheme is a network-controlled-based, then the MIIS server additionally should have the ability to make network selection. However, in this paper we consider our proposed handover scheme is a network-assisted terminal-controlled based, so the network selection is shifted to terminal side.

Figure 2 presents our network model. The general architecture is mainly based on evolved packet core (EPC) structure, which can be considered as an evolution of the legacy GPRS architecture with additional features to improve performance. A WiMAX's access service network (ASN) is directly connected to MIIS gateway (GW) as trusted access. On the other hand, the MIIS servers are located in the network and a chord provides a decentralized database among the MIIS servers to maintain information of neighboring networks and responds to the requests from an MN. In this MIIS architecture, one important feature is that the information provided by the MIIS server not only relates

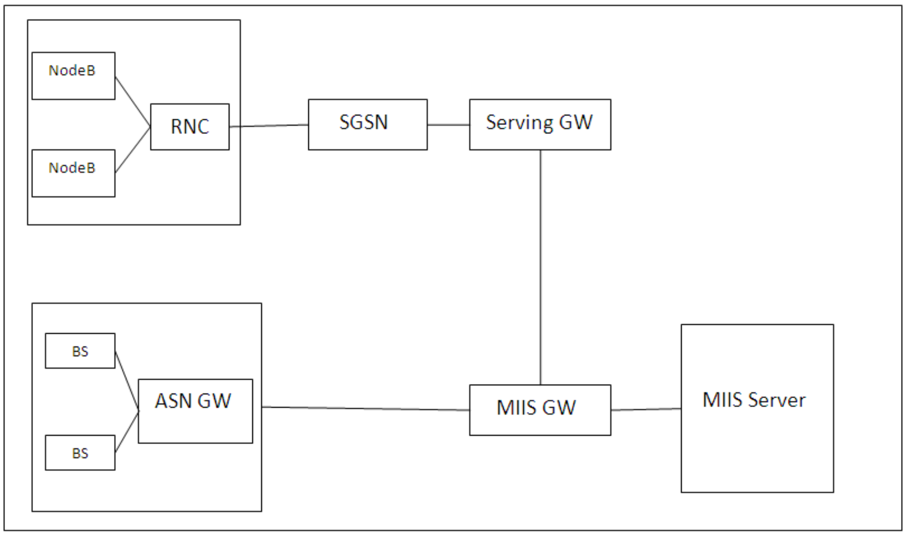

FIGURE 2. Our network model

to the technology in use, but any surrounding available technologies can also be accessed. For instance, an MN connected to an 802.xx network such as WiMAX network, will be able to obtain information about UMTS network, without the need of activating its UMTS interface.

To describe the architecture and functionalities of our proposed MIIS, several assumptions are made. First, an MN can measure its location timely using some localizing technologies, for example, received signal strength indication (RSSI) tracking and global positioning system (GPS). Second, we assume that the number of always available networks for an MN is limited. This is because the scanning coverage of the MN is finite. Third, the information contained in MIIS server can be shared by peers. These assumptions are rational as they are enabled by current technology and they can easily be extended. The overall handover procedure can be divided into three stages: neighbor network discovery, network selection and handover execution. In this work, the MIIS server is mainly responsible for network discovery stage. Figure 3 gives the internal architecture of our proposed MIIS server. It is composed of four sub-components: local database (LD), neighbor network discover agent (NNDA), information collector (IC), and the MIH Module.

Local Database (LD) contains an information manager and stores various local information elements (IEs). These IEs can be shared with peers and they are can be divided into five groups: general information (GI) such as network type, operator identifier or service provider identifier, access network specific information (ANSI) which is related to QoS information and roaming partners, point-of-attachment specific information (PSI) which comprises aspects such as MAC address of the PoA, geographical location, data rate, and channel range, high level information (HLI) which includes the information about the available services for each PoA such as the IP configuration methods, the number of subnets supported by this PoA, a list of all supported services on this PoA, and other information (OI) like vendor specific information or services which can be added to our proposed MIIS server. Information manager is located within database to manage various activities of the IEs. Meanwhile, it serves as an interface to interact with other components in MIIS server.

NNDA leverages on the comparison of the information in either local database or decentralized database among MIIS servers and the MN location information, giving a number of networks necessary to be spectrum scanned and channel synchronous.

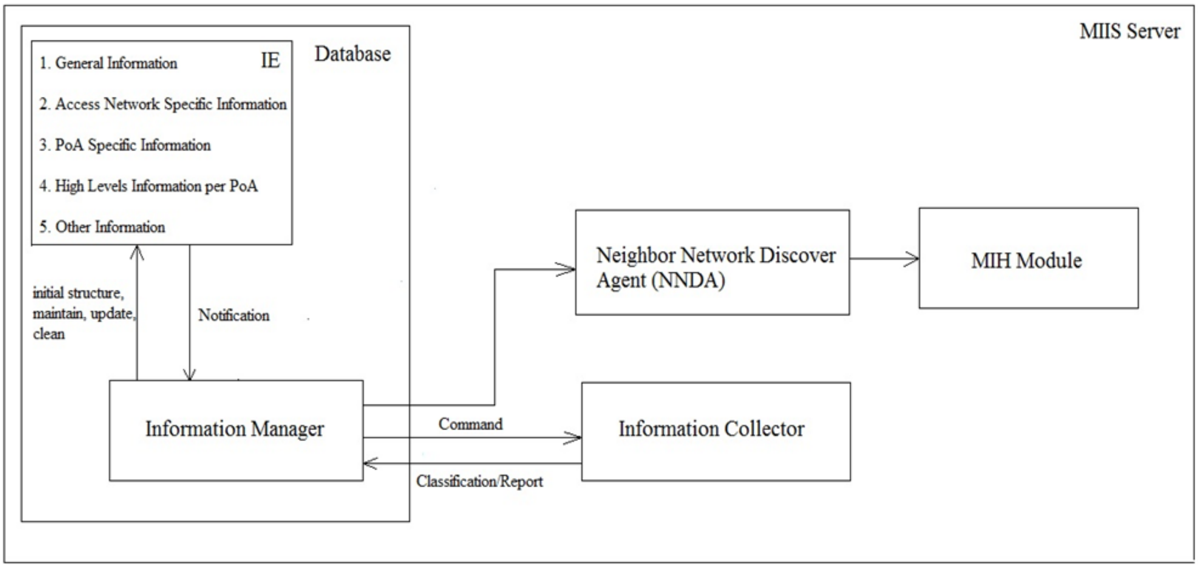

FIGURE 3. Internal architecture of our proposed MIIS server

IC takes order from information manager to collect measurements by MN from radio network controller (RNC) or BS, and reports to information manager.

MIH Module is the interface of the MIIS server. It is responsible for communication among other network entities through MIH_NET_SAP.

3.2. **The hierarchical distributed hash tree based MIIS servers.** In this paper, chord was used to distribute database among MIIS servers. However, it can be replaced by any other DHT such as regular and flat DHTs. The reason for choosing chord rather than regular and flat DHTs, is because in regular and flat DHTs, the location of each peer is unknown and can be anywhere in the world. This imposes that a neighboring MIIS server in the DHT might be actually locating at the other side of the world, which introduces more undesirable lookup delay. However, chord provides a key and maps onto an MIIS server. The data location can be implemented on the chord by associating each data to the key. That means in the proposed architecture, MIIS server does not store the data, but a reference that points in which server the data is stored. Figure 4 gives the topological overview of the proposed architecture.

Additionally, we deployed a hierarchical architecture in this paper, by which the overall system can be enhanced in the aspects of resilience and scalability. In fact, almost all the largest systems in the world are built hierarchically. We adopt three layers in hierarchy. Peers in each layer are grouped based on their mutual round trip time (RTT), which also can be used to represent different geographical regions. Meanwhile, we assume the connection between MIIS servers is reliable. This assumption is enabled in current technology. Each MIIS server stores it own data and interconnected mutually. Therefore, all the data that are distributed in the chord can be accessed by anybody. In order to evaluate the lookup delay for a specific data in this architecture, we define the lookup delay (T_{LD}) as Equation (1).

$$T_{LD} = T_{MN \to MIIS\ SERVER} + T_{PROCESS} + T_{MIIS\ SERVER \to MN} \quad (1)$$

$T_{MN \to MISS\ SERVER}$ is the one way delay between MN and MIIS server, $T_{MIIS\ SERVER \to MN}$ is the delay in another direction, and $T_{PROCESS}$ is the time used to look for a specific data in a layer. Therefore, to each MN-MIIS server peer, it is easy to understand that $T_{MN \to MIIS\ SERVER} \approx T_{MIIS\ SERVER \to MN}$. We use $T_{MN-MIIS\ SERVER}$ to represent these

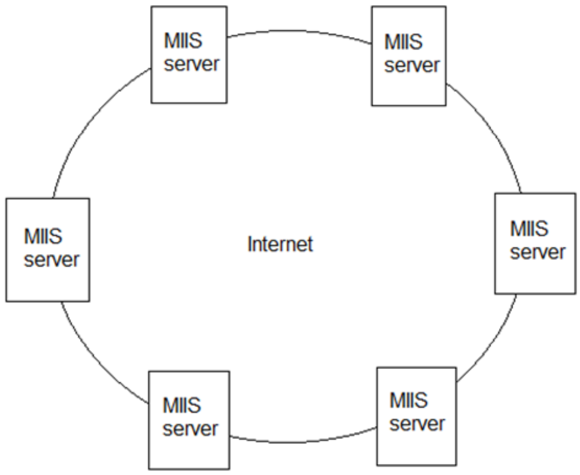

FIGURE 4. Topology of the proposed architecture

two parameters for simplicity discussion.

$$T_{LD} = 2T_{MN-MIIS\ SERVER} + T_{PROCESS} \tag{2}$$

From Equation (2), we can obtain the lookup delay of each layer:

$$T_{LD(Layer1)} = 2\left(T_{MN\to PoA} + T_{PoA\to MIIS\ SERVER}\right) + T_{PROCESS(Layer1)} \tag{3}$$

$$\begin{aligned} T_{LD(Layer2)} &= T_{LD(Layer1)} + T_{MIIS\ SERVER(Layer1)\to MIIS\ SERVER(Layer2)} \\ &\quad + T_{MIIS\ SERVER(Layer2)\to MIIS\ SERVER(Layer1)} + T_{PROCESS(Layer2)} \\ &= T_{LD(Layer1)} + 2\left(T_{MIIS\ SERVER(Layer1)-MIIS\ SERVER(Layer2)}\right) \\ &\quad + T_{PROCESS(Layer2)} \end{aligned} \tag{4}$$

$$\begin{aligned} T_{LD(Layer3)} &= T_{LD(Layer2)} + T_{MIIS\ SERVER(Layer2)\to MIIS\ SERVER(Layer3)} \\ &\quad + T_{MIIS\ SERVER(Layer3)\to MIIS\ SERVER(Layer2)} + T_{PROCESS(Layer3)} \\ &= T_{LD(Layer1)} + 2\left(T_{MIIS\ SERVER(Layer2)-MIIS\ SERVER(Layer3)}\right) \\ &\quad + T_{PROCESS(Layer3)} \end{aligned} \tag{5}$$

$T_{MN\to PoA}$ is the one way delay between MN and Point of Attachment, $T_{PoA\to MIIS\ SERVER}$ is the one way delay between Point of Attachment and MIIS server, and $T_{PROCESS}$ is the time used to look for a specific data in a layer. $T_{PROCESS(Layer1)}$, $T_{PROCESS(Layer2)}$ and $T_{PROCESS(Layer3)}$ are more complicated to be calculated. We define $T_{PROCESS(Layer1)}$ as Equation (6).

$$T_{PROCESS(Layer1)} = \alpha(\tau + 3)T_{MIIS-MIIS} \tag{6}$$

where τ is the average number of hops to find the specific data in DHT, and it is set to 2 in this paper. $T_{MIIS-MIIS}$ is the one way delay between two MIIS servers in the same layer. The term $(\tau + 3)$ is resulted when the value of a key is located after τ hops. The value of the key will be sent to the one more hop MIIS server, which will contact the MIIS server that stores the specific data.

For layers 2 and 3, $T_{PROCESS(Layer2)}$ and $T_{PROCESS(Layer3)}$ can be defined as Equations (7) and (8).

$$T_{PROCESS(Layer2)} = \alpha(\tau + 3)T_{MIIS-MIIS(Layer1)} + \beta(\tau + 3)T_{MIIS-MIIS(Layer2)} \tag{7}$$

$$T_{PROCESS(Layer3)} = \alpha(\tau + 3)T_{MIIS-MIIS(Layer1)} + \beta(\tau + 3)T_{MIIS-MIIS(Layer2)}$$

$$+\gamma(\tau+3)T_{MIIS-MIIS(Layer3)} \tag{8}$$

where α, β and γ are the probabilities of the specific data located in layers 1, 2 and 3. $T_{MIIS-MIIS(Layer1)}$, $T_{MIIS-MIIS(Layer2)}$ and $T_{MIIS-MIIS(Layer3)}$ are the one way delay in different layers. We assume $T_{MIIS-MIIS(Layer1)} \approx T_{MIIS-MIIS(Layer2)} \approx T_{MIIS-MIIS(Layer3)}$. Meanwhile, we assume α, β and γ follow the Pareto principle; hence they are set the values to 0.8, 0.16 and 0.04, respectively.

Section 5 will give the performance evaluation and analysis on the lookup delay (T_{LD}) of the proposed hierarchical chord that works as the MIIS server. The evaluation is based on Equations (3)-(5).

3.3. **The proposed neighbor network discovery using MIIS server.** The detailed procedure of our proposed neighbor network discovery using MIIS server is shown in Figure 5.

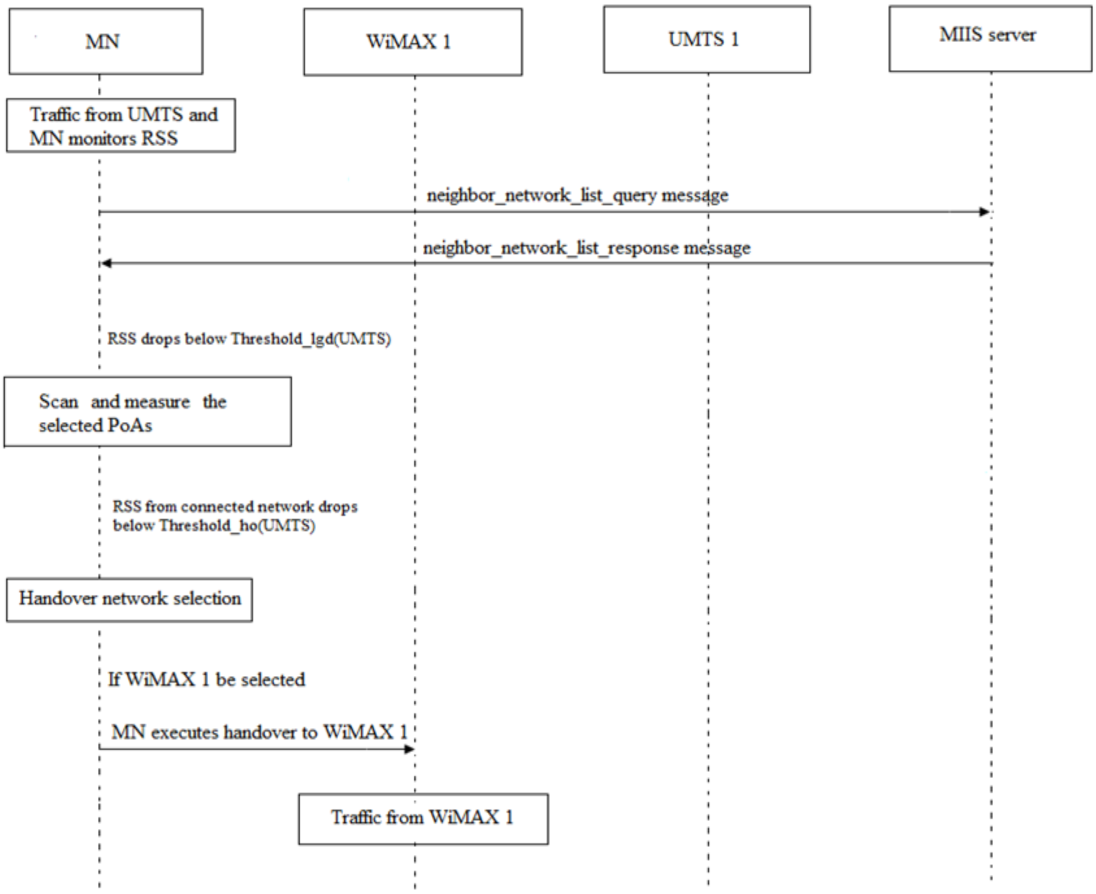

FIGURE 5. Procedure of our proposed neighbor network discovery by using MIIS server

As mentioned earlier, an MN always monitors the RSS from the connected networks in order to determine if a handover is necessary. When the MN moves toward the boundary of the coverage area, a drop in the RSS is inevitable. There are several thresholds used in the proposed algorithm:

i. $Threshold_{\_lgd(UMTS)}$ is used to trigger *link_going_down* event in the UMTS network,
ii. $Threshold_{\_ho(UMTS)}$ is the handover threshold in the UMTS network,
iii. $Threshold_{\_lgd(WiMAX)}$ is used to trigger *link_going_down* event in the WiMAX network,
iv. $Threshold_{\_ho(WiMAX)}$ is the handover threshold in the WiMAX network.

The values of $Threshold_{\_lgd(UMTS)}$ and $Threshold_{\_lgd(WiMAX)}$ are set based on the coefficient of received power before sending in each network. And the value of $Threshold_{\_ho(UMTS)}$ and $Threshold_{\_ho(WiMAX)}$ are set based on the link handover imminent in each network.

In order to conveniently describe the procedure of our proposed neighbor network discovery scheme, Table 1 gives the definition of the messages that are used in the proposed method.

We take an example in which MN is connected to a UMTS network and handover to a WiMAX network. Initially, on-going session is transmitted to MN via UMTS network. Meanwhile, MN periodically sends *neighbor_network_list_query* message to the MIIS server. The MIIS server then provides the probable neighbor networks and the network-related information of the neighbor networks to MN through the PoA-specific IEs in the *neighbor_network_list_response* message. When the RSS value drops below $Threshold_{\_lgd(UMTS)}$, the MN will be triggered to scan each candidate network to obtain the link-related information. After that, when the RSS value further drops below $Threshold_{\_ho(UMTS)}$, the MN activates the network selection algorithm to evaluate the suitability of each network depending on our proposed network selection scheme which will be described in Section 4. After completing the selection, the MN executes the handover to the target network with the highest priority. Table 2 gives a summary of the IEs we have implemented in the proposed MIIS server.

Table 1. Definition of the messages used in the proposed network discovery mechanism

neighbor_network_list_query	This message is sent by MN to MIIS server to request neighboring network list when a handover is triggered and it includes the location of the MN.
neighbor_network_list_response	This message is used by MIIS server to respond MN's query and it contains the neighboring network information.

Table 2. The summary of the IEs implemented in the proposed MIIS server

General Information	Access Network Specific Information	PoA Specific Information	High Levels Information per PoA	Other Information
TYPE_IE_LIST_OF_NETWORKS	TYPE_IE_NUMBER_POA	TYPE_IE_POA_ADDRESS	TYPE_IE_POA_SUBNET_INFORMATION	Vendor specific
TYPE_IE_NUMBEB_OF_OPERATORS	TYPE_IE_OPERATOR_INDENTIFIER	TYPE_IE_POA_LOCATION	TYPE_IE_POA_CAPABILITIES	N/A
TYPE_IE_LIST_OF_OPERATORS	TYPE_IE_ROAMING_PARTNERS	TYPE_IE_POA_DATA_RATE	N/A	N/A
N/A	TYPE_IE_COST	TYPE_IE_POA_PHY_TYPE	N/A	N/A
N/A	TYPE_IE_NETWORK_SECURITY	TYPE_IE_POA_MAC_TYPE	N/A	N/A
N/A	TYPE_IE_QOS	TYPE_IE_POA_CHANNEL_RANGE	N/A	N/A

Additionally, it is worthy to note that in the *neighbor_network_list_response* message, one useful IE for PoA discovery is TYPE_IE_POA_LOCATION, which contains the geographical location of PoAs. In this paper, the MIIS server, depending on the location of MN, responds a selected neighbor networks' information to MN. This location-based discovery approach is similar to the operation in [4], which can significantly reduce the unnecessary scanning operations. In channel information respects, the proposed MIIS defines TYPE_IE_POA_CHANNEL_RANGE, which indicates the channel range of PoAs in MHz, and assists MN to know which channels the neighbor PoAs are operating on. After receiving the *neighbor_network_list_response* message, MN scans the selected PoAs in a certain channel range and measures RSS. Therefore, we can see that in our proposed scheme, MN activates its WiMAX interface only when the neighbor networks list includes WiMAX networks; this obviously reduces the power consumption. The handover process for the MN in a WiMAX network travelling to UMTS network is similar to the previous case.

4. **The Proposed Handover Decision Method.** As mentioned in Section 3, when the RSS value from the connected network drops below the handover threshold ($Threshold_{\_ho(UMTS)}$ or $Threshold_{\_ho(WiMAX)}$) the MIIS determines the best target network based on our proposed network selection scheme called load-aware network capacity estimation algorithm. In this paper we consider a scenario with two types of network: UMTS and WiMAX networks, but the proposed method can be easily extended to other types of network as well. Furthermore, the proposed load-aware network capacity estimation algorithm is compatible with all the functions in the original MIH framework. Since different networks have different topologies and characteristics, it is insufficient to use a single uniform method to evaluate and to compare their network capacity performances directly. Our proposed scheme evaluates the capacity of the UMTS and the WiMAX networks separately to indicate the need of handover. Although we evaluate the performance of the proposed scheme in our designed scenario only, we believe good results can be obtained in other topologies as well because the complexity of the designed scenario and the parameters are close to the real world implementation.

4.1. **Capacity estimation algorithm for the UMTS system.** The most common form of UMTS uses wideband code division multiple access (W-CDMA), which is an interference limitation system when a frequency division multiplexing factor of 1 is used. It is necessary to estimate the capacity provided by each NodeB; the capacity of a WCDMA cell can be estimated as follows [20].

The energy per bit to noise power spectral density ratio (E_b/N_0) is defined as the bit strength of a user divided by the interference spectral density, as given in Equation (9).

$$\left(\frac{E_b}{N_0}\right)_j = \left(\frac{W}{v_j R_j}\right)\left(\frac{RSS_j}{TX_{total} - RSS_j}\right) \tag{9}$$

where W is the chip rate, RSS_j is the received signal strength of user j, v_j is the activity factor of user j which is usually set to 0.58 for voice traffic and 1 for data traffic, R_j is the bit rate of user j, TX_{total} is the total transmitted signal strength of the NodeB. The first term on the right side of the equation indicates the processing gain of user j, and the second term indicates the signal to interference ratio. From Equation (9), we can derive the relationship between the received signal strength of user j (RSS_j) and the total transmitted signal strength of the NodeB (TX_{total}), as given in Equation (10). The first term on the right side of Equation (10) can be treated as load factor of user j.

$$RSS_j = \left(\frac{1}{\frac{W}{v_j R_j \left(\frac{E_b}{N_0}\right)_j} + 1} \right) TX_{total} \tag{10}$$

Usually, we define $RSS_j = L_j TX_{total}$, where L_j is the load factor of user j connecting in the cell and can be denoted as $\Delta\eta$ as given in Equation (11).

$$\Delta\eta = L_j = \left(\frac{1}{\frac{W}{v_j R_j \left(\frac{E_b}{N_0}\right)_j} + 1} \right) \tag{11}$$

The total load factor for all users connecting to a nodeB, η, is given by Equation (12).

$$\eta = [(1 - \mu) + i] \sum_{j=1}^{N} L_j \tag{12}$$

where μ is the orthogonal factor of the cell, which usually takes a value of 0.5, i is the interference rate from neighbor cells, which is set to 0.55 due to the use of omnidirectional antenna in the cells. A value of η close to 1 indicates the capacity of a nodeB reaching the saturation.

4.2. **Capacity estimation algorithm for WiMAX system.** Different from the UMTS system, the capacity of a WiMAX base station is estimated according to its throughput, as calculated by using Equation (13) [20].

$$Throughput = (n \times BW \times b_m \times c_r \times N_{utilFFT}) \times \left(\frac{1}{N_{FFT} + \frac{N_{FFT}}{T_g}} \right) \tag{13}$$

where n is the sample rate, BW is the channel spacing, b_m and c_r are the order of modulation and coding, respectively, $N_{utilFFT}$ is the number of data subcarriers which is equal to 384 when the partial usage of subchannels use 5MHz bandwidth, N_{FFT} is the number of Fast Fourier Transform samples, and T_g is the cyclic prefix for the OFDMA system which is equal to 1/8.

For handover from WiMAX to UMTS, our proposed scheme considers the total load factor of the network, the network with less value of η, which has the higher priority is chosen. On the other hand, when handover occupied from UMTS and WiMAX, throughput of each WiMAX network is the domination factor and the one with the maximum throughput is chosen.

The details of the overall neighbor networks discovery and handover decision process from UMTS to WiMAX is given in Figure 6. For handover from UMTS to WiMAX, when the MN moves toward the edge on the coverage area, two stages are involved. First, when the value of RSS from connected UMTS network drops below $Threshold_{\_lgd(UMTS)}$, MN scans the selected neighbor networks to obtain the link information. Second, a handover is initiated when value of RSS drops below $Threshold_{\_ho(UMTS)}$. At this stage, the MN calculates the network capacity of current network and nearby the UMTS and the WiMAX networks based on Equations (12) and (13). These values are compared. Generally, the proposed scheme prioritizes horizontal handover over vertical handover because horizontal handover is less complicated and introduces lower delay. With this in mind, a neighbor UMTS network with RSS higher than $Threshold_{\_lgd(UMTS)}$ and the best network capacity is chosen. Otherwise, a vertical handover is performed by choosing a WiMAX network with the greatest value of network capacity and RSS greater than

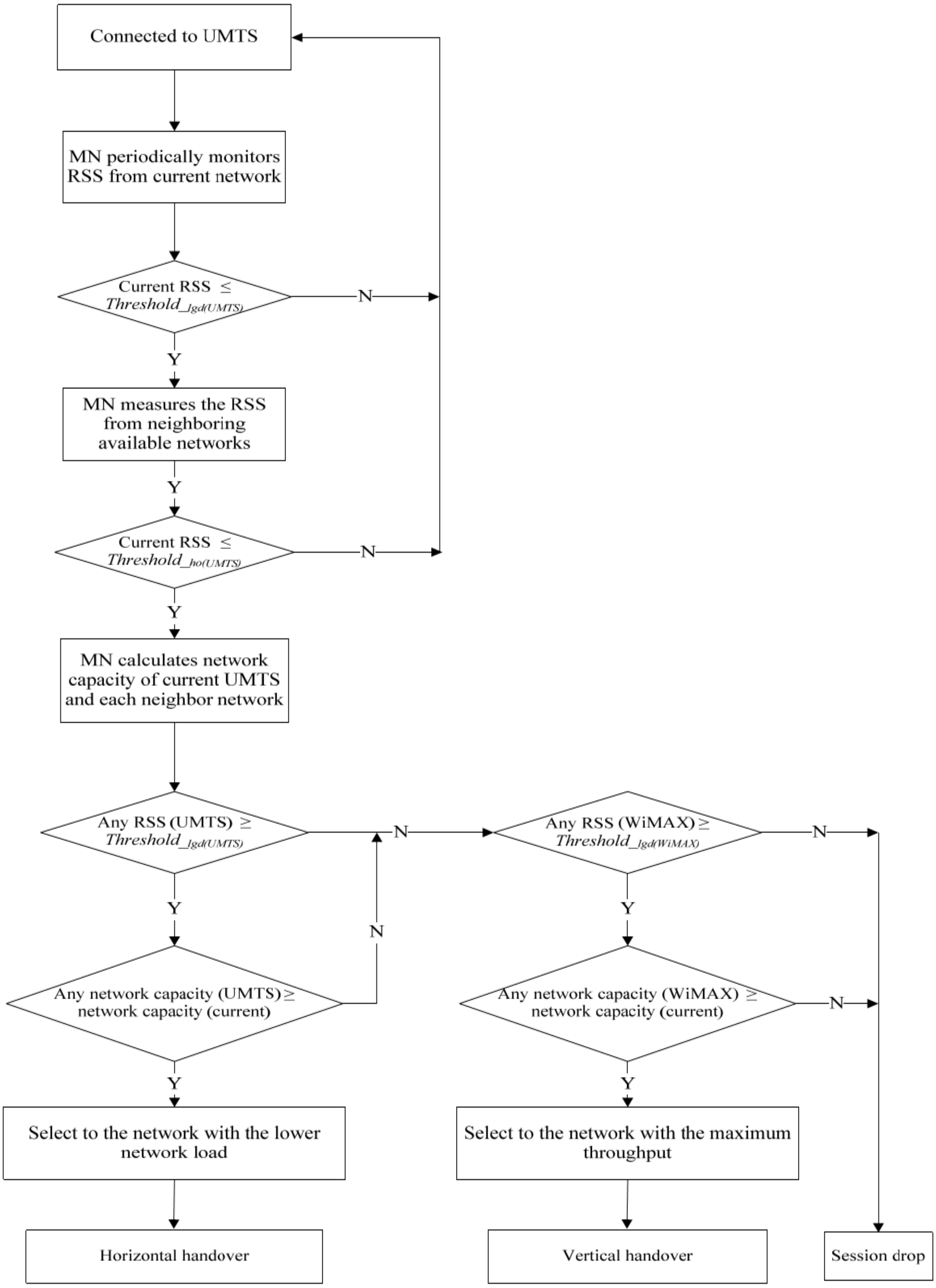

Figure 6. Handover from UMTS to WiMAX

$Threshold_{\_lgd(WiMAX)}$. The session will only be dropped under the worst case scenario, in which both UMTS and WiMAX networks fail to fulfill the above requirements.

The handover process for an MN in a WiMAX network travelling to another network is similar to the previous case. The MN scans the neighbor networks to obtain the link information when its RSS value drops below $Threshold_{\_lgd(WiMAX)}$. Subsequently, if its RSS value drops below $Threshold_{\_ho(WiMAX)}$, a handover process is initiated by first calculating its current network capacity, and the capacity values for neighbor networks. Again, horizontal handover has higher priority than vertical handover for the reason explained above.

5. **Simulation and Results.**

5.1. **Simulation model.** In this paper, NS2 (version 2.31) [21] with the MIH module developed by NIST [22] was used to perform the simulation studies. For performance evaluating purpose, we measure the packet loss rate, throughput and handover delay when handover occurs. Meanwhile, we give an evaluation on the lookup delay for the proposed hierarchical chord-based architecture of MIIS servers. Data traffic from the correspondent node (CN) to the MN. The topology used consists of twenty UMTS cells overlaying with twenty WiMAX cells to simulate a heterogeneous network as shown in Figure 7. We assume that the radius of WiMAX cell is a bit smaller than UMTS's. The radius of the coverage area for an UMTS cell was 3 km from NodeB while a WiMAX cell covered an area with radius 2 km from the BS. The CN was connected to the backbone with a data transmission rate of 100 Mbps and a link delay of 30 ms. All NodeBs were connected to an access router and all the BSs were connected to another access router with a data transmission rate of 100 Mbps and a link delay of 30 ms. Both the access routers communicate to the CN via a router with a link with 15 ms delay. In addition, MIIS servers were connected to the routers with a data transmission rate 10 Mbps. We set the number of MN to be 200, 400, 600, and 800, respectively, and randomly located at the center of the topology within a rectangle area of 16 km by 12 km and communicate to each other with a random move speed distributed normally between 3 and 30 m/s. We

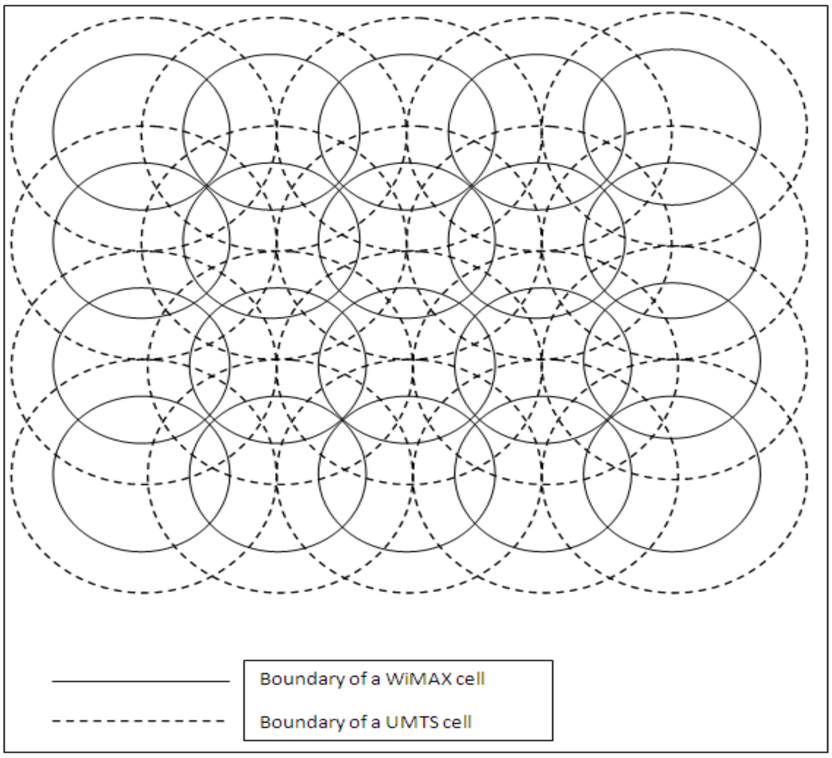

FIGURE 7. Simulation topology

used UDP as the transport protocol and CBR at the application layer. In this simulation, we compared the proposed scheme with the basic MIH scheme and some other proposals. Table 3 gives the simulation parameters.

TABLE 3. Simulation parameters

Simulation parameter	value
Simulation time	7200 sec
Number of networks	40
Number of MIIS servers in lowest layer	8
Number of MIIS servers in second layer	4
Number of MIIS servers in upper layer	2
Number of MN	200, 400, 600, 800
MN speed	3 m/s – 30 m/s
Mobility model	Random waypoint

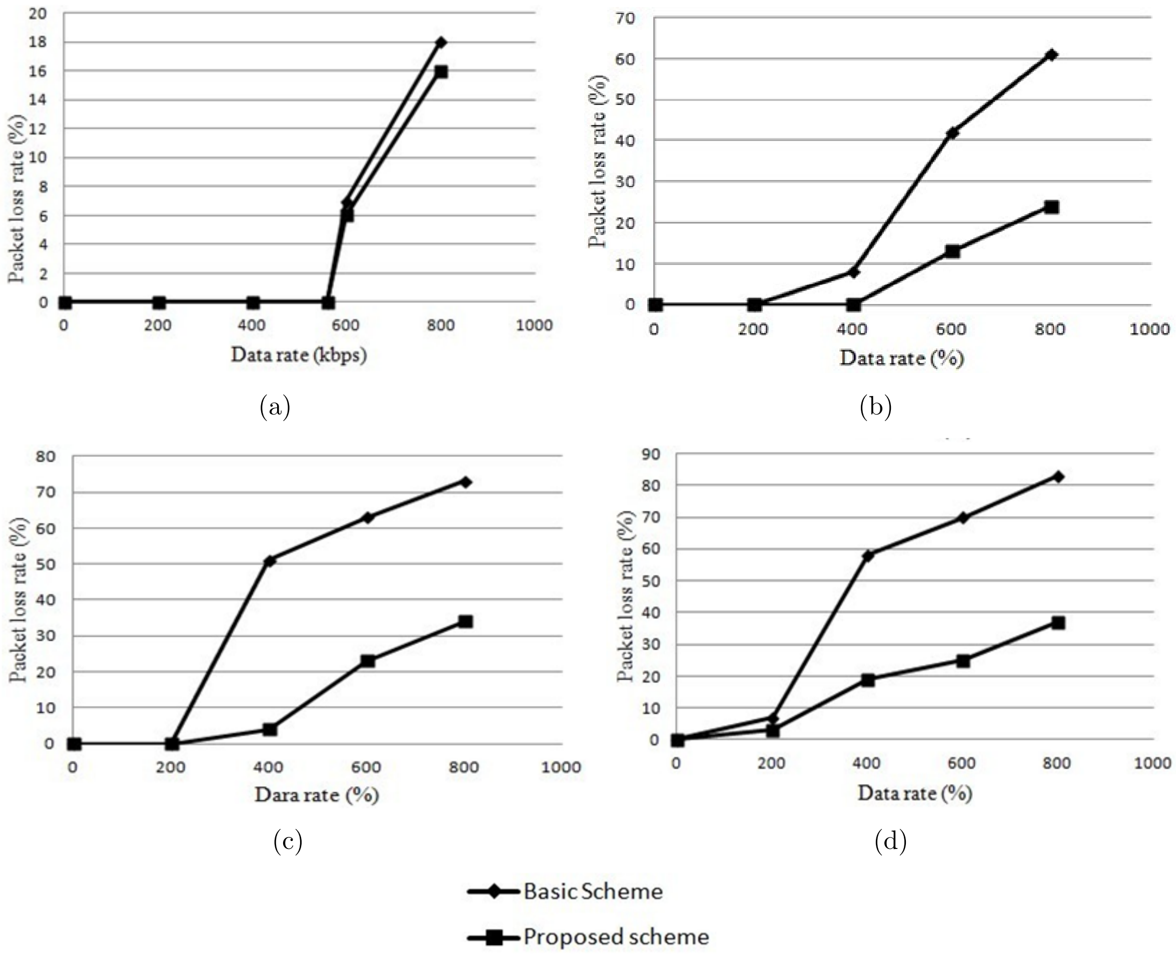

FIGURE 8. Packet loss rate of the overall system versus date rate: (a) number of MN is 200; (b) number of MN is 400; (c) number of MN is 600; (d) number of MN is 800

5.2. **Results and discussion.** The parameters used in performance evaluation are the packet loss rate, throughput, handover delay and MIIS server lookup delay. Figure 8 shows the packet loss rate during handover execution for different number of MNs deployed in scenario. It can be observed that the proposed method always has a lower packet loss than the basic scheme. As the data rate increases, the packet loss increases in both schemes, but in the basic scheme, the value of packet loss is as high as 83% at the highest data rate of 800 kbps and 80 MNs are deployed. The proposed scheme controls the packet loss rate at a slower rate and the packet loss rate is only about 37% at the highest data rate and the largest amount of MNs. As the number of MN increases, the network load increases, the load at each cell is unbalanced and so when an MN moves from one location to another location, the basic handover scheme that makes handover decision solely based on RSS but not consider network capacity may make a handover to a network that is lacking in resources, and this causes more packet loss. On the other hand, the proposed scheme allows sessions to be handover to network with sufficient resources, which drastically reduces the packet loss rate.

Figure 9 gives the average packet loss rate of an MN in simulation versus the different number of MNs deployed. From the simulation results, the proposed scheme gives better performance with an average packet loss of 0.784% as compared to 2.09% using the basic scheme. According to IEEE 802.20 Working Group recommendations [24], packet loss rate should be less than 2% for mobile voice service, 1% for video over mobile networks, and 0.1% for interactive videos. Looking at the results, we can see that the proposed scheme fully fulfills the requirement of mobile voice service. If the number of MNs present in the topology is less than 400, the proposed scheme satisfies the requirement of video over mobile networks as well. Furthermore, if there are less than 20 MNs in the topology, the proposed scheme is also working well for interactive video service. Contrarily, the basic scheme can satisfy the requirement of mobile voice service only if there are less than 20 MNs in the network.

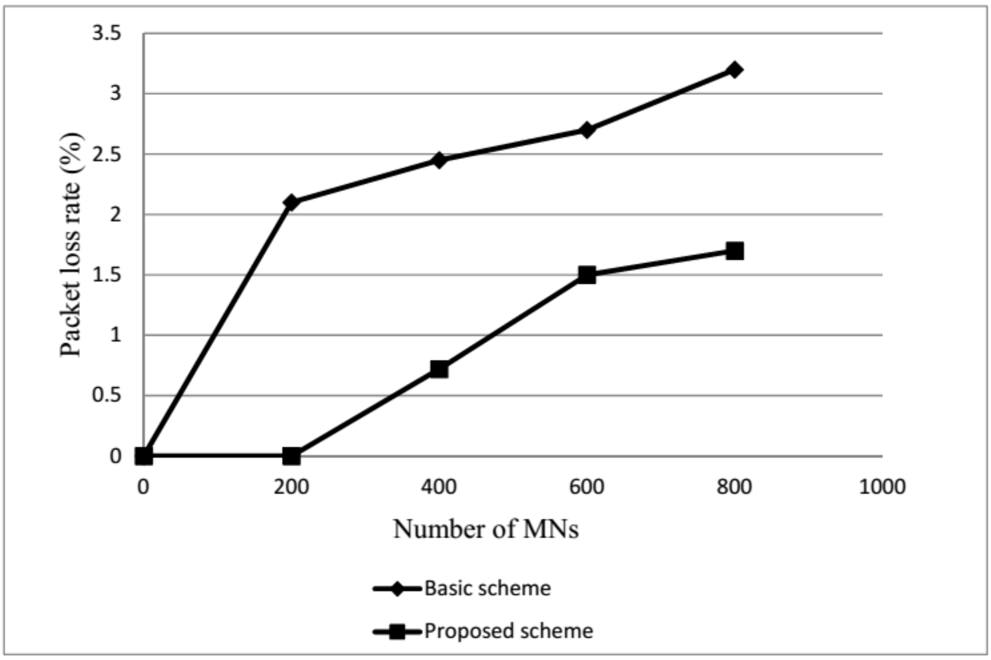

FIGURE 9. Average packet loss rate of MN versus the different number of MNs

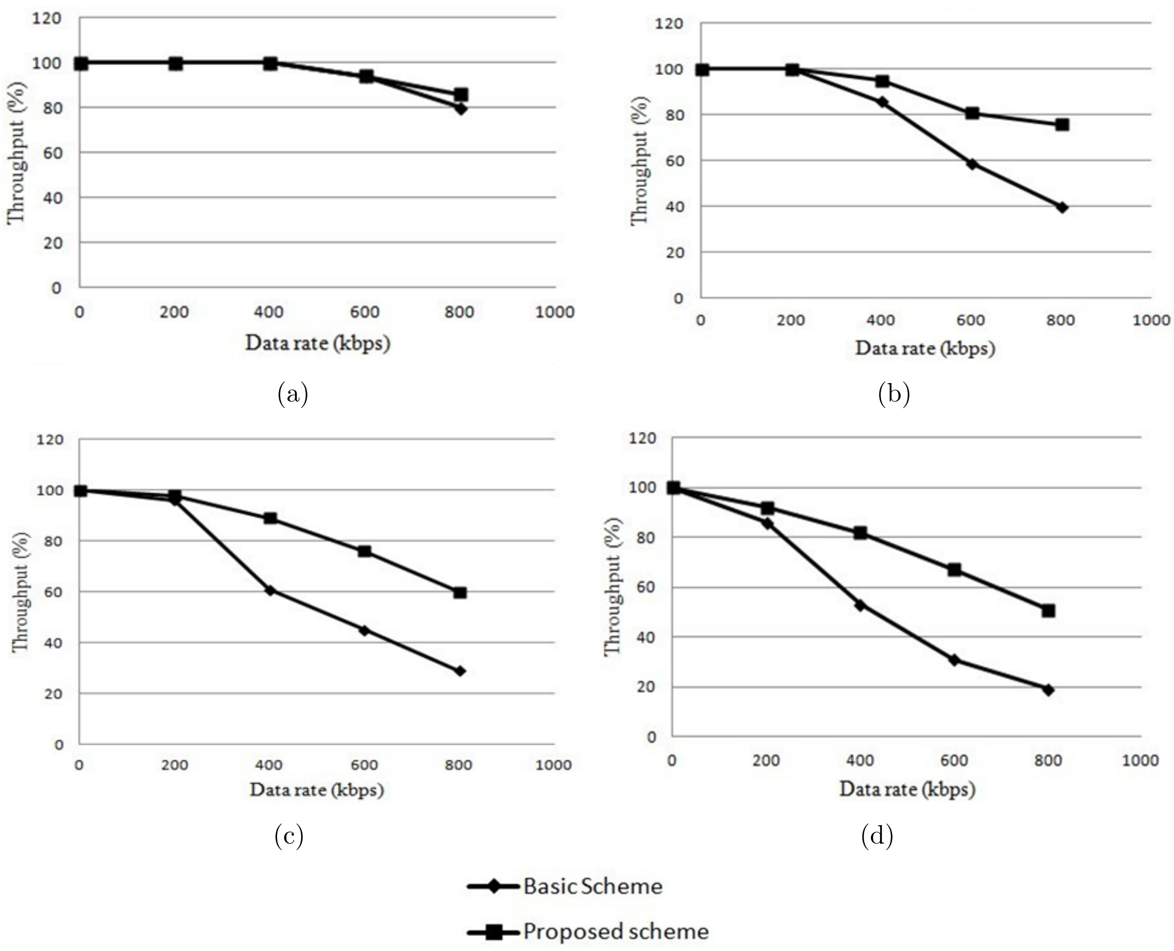

Figure 10. Total throughput versus data rate: (a) number of MNs is 200; (b) number of MNs is 400; (c) number of MNs is 600; (d) number of MNs is 800

Figure 10 gives the total throughput versus various data rates with different number of MNs. From the simulation results, the proposed scheme gives better performances than the basic scheme in all data rates and the number of MNs deployed in the topology. There are two reasons contributing to this superior performance. First, the proposed method gives higher priority to horizontal handover over vertical handover, which is faster and less complex. This action could save a lot of network resources. Second, network capacity is also considered in choosing the most suitable network to handover the connection. This consideration not only reduces the probability of handover failure, but also distributes the workload more evenly among the networks. As the number of MNs increases from 200 to 800, the average throughput reduces by only 17.6% in the proposed schemed, but as high as 37% in the basic scheme. This finding is important because it shows that the proposed scheme is more robust and has less impact on its throughput caused by different workload.

Figure 11 illustrates the average throughput of MN in simulation versus the number of MN deployed. It can be observed a drop in the throughput as the number of MNs increases because the network load increases, the load at each cell is unbalanced. The basic handover scheme that makes handover decision without considering the network capacity may make a handover to a network without resources, lead to a drop in throughput. On

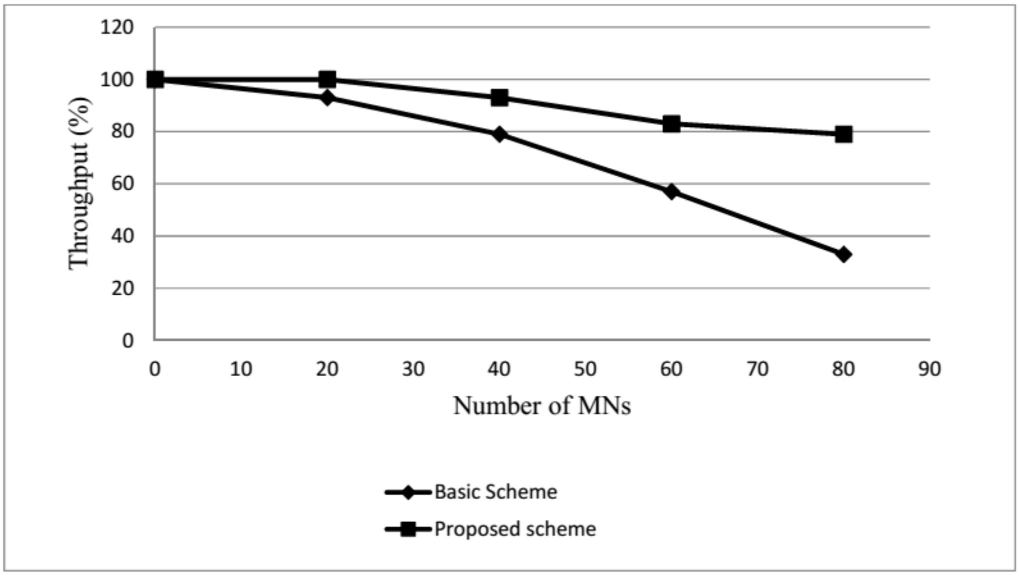

FIGURE 11. Average throughput of MN versus the different number of MNs

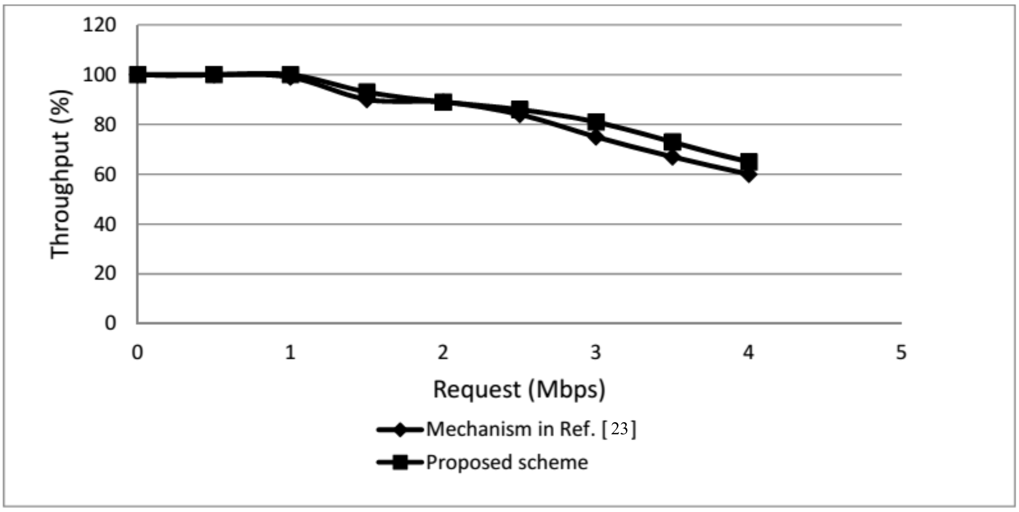

FIGURE 12. Comparison of our proposed mechanism with mechanism in Ref. [23] on the throughput of the system

the other hand, it is obvious that the proposed scheme gives a more stable performance regardless of the number of MNs.

Furthermore, Figure 12 illustrates the comparison of our proposed mechanism with [23] on the throughput of the system. We adopt our proposed mechanism to the scenario of [23], in which there is a three-cell overlay network each with different data rate: 1 Mbps, 1.5 Mbps and 2 Mbps respectively and the node moves at the speed of 10 m/s. From the result, we can find that our proposed scheme is merely a bit better than the mechanism in [23], which is because the scenario simply cannot show the whole potential ability of our proposed mechanism. And also in our further study, we find that as the mobility increases, the throughput of [23] drops faster compared to our mechanism. From this aspect, we believe that this is because the design idea of vertical handover decision algorithm in [23] is mainly focusing on the covered cost function and finally an optimization protocol is added. However, this work has not separately considered each network's capability and conditions, even from the equation of the cost function; it is obvious that there are a lot of assumptions having been made, since it is not precise. On the other hand, our proposed mechanism is more accurate.

Figure 13 shows the handover delay between UMTS and WiMAX versus data rate. In this paper we define the handover delay as the time between the last packet received from the previous PoA and the first packet received from the new PoA. As the data rate increases, the handover delay increases in the both scheme. The proposed scheme shows a better performance, because the handover is accelerated by knowing the number of selected surrounding PoAs and which channels they are operating on before handover, instead of the MN periodically scanning all the operating channels to find the available PoAs as used in the conventional scheme. From IEEE 802.20 working group recommendations [24], handover delay should be less than 150 ms for mobile voice, 280 ms for non-interactive video. For interactive video, a handover delay of 100 ms is acceptable for class 0 and up to 400 ms for class 1 according to ITU-T Recommendation Y.1541 [24]. From the results, the increases of handover delay are smooth with a maximum handover time of 171 ms while the highest data rate and maximum amount of MNs are deployed. The results indicate that our proposed scheme satisfies the acceptable values for both non-interactive and interactive video services regardless of data rate and the number of MNs. For mobile voice service, if the number of MNs deployed is less than 800, our proposed scheme also enables to achieve the requirement. A further comparison is made with [25], in which the best handover time reported is between 400 ms and 500 ms; our proposed scheme still gives a shorter handover time in all cases.

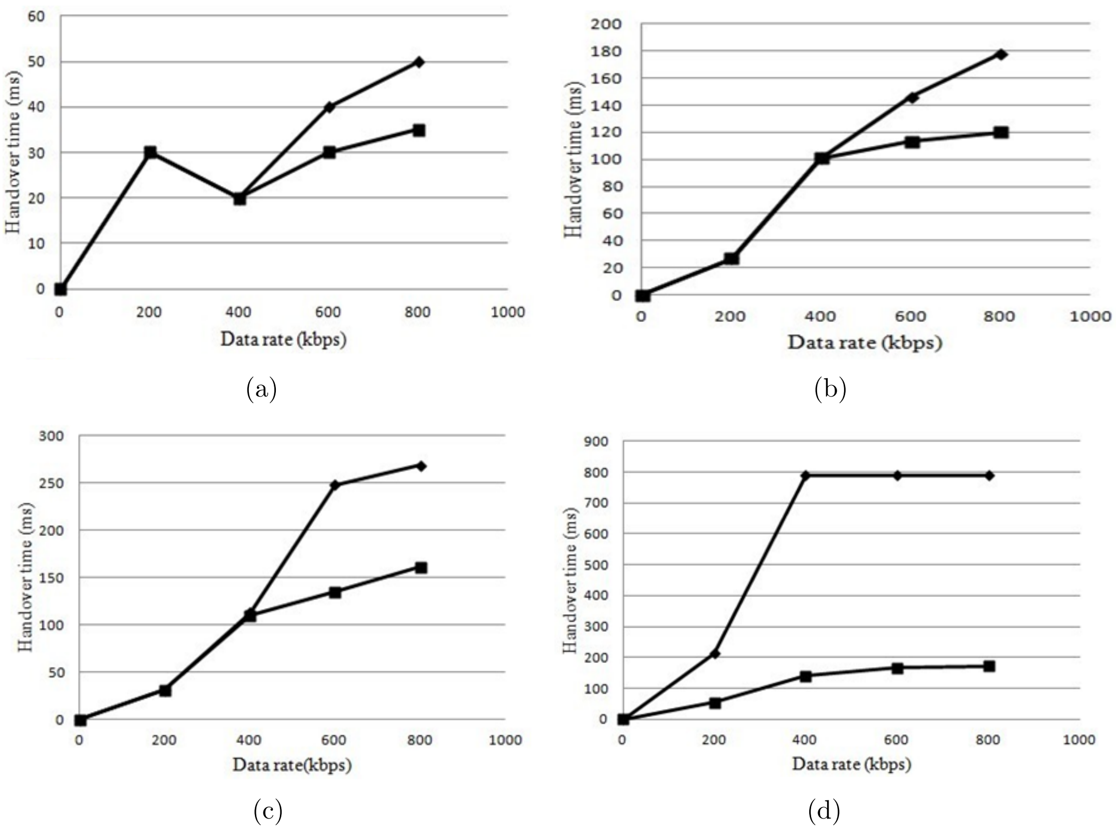

FIGURE 13. Handover delay between UMTS and WiMAX versus data rate: (a) number of MNs is 200; (b) number of MNs is 400; (c) number of MNs is 600; (d) number of MNs is 800

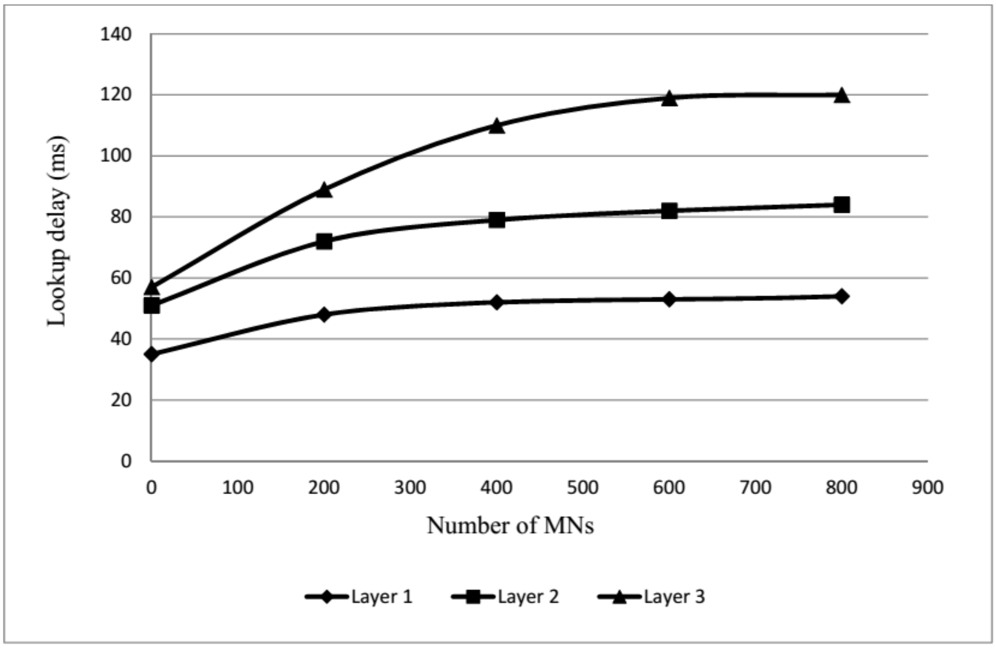

FIGURE 14. The lookup delay versus number of MNs

Figure 14 presents the influence of the number of MNs to the lookup delay of the proposed architecture of MIIS servers. The evaluation is based on Equations (3)-(5). It can be observed that layer 3 has the longest lookup delay with average of 99 ms while layer 1 has the shortest lookup delay of average 48.4 ms. Another important finding is that in all three layers, the lookup delay increases rapidly while the number of MNs is small, but it tends to be stable after a larger number of MNs were deployed. This indicates our proposed architecture has the scalability.

6. **Conclusions.** In this paper we presented a new architecture and functionalities of MIIS servers which are organized in hierarchical chord architecture to enhance the resilience, fault tolerance and scalability of the overall system. Meanwhile, a load-aware network capacity estimation network selection scheme was proposed to address the challenge of seamless connectivity in heterogeneous environment. Through extensive simulations, it shows that the proposed scheme enhances the MN experience of handover in terms of packet loss rate, throughput and handover delay. Finally, we also give an evaluation on the lookup delay for the proposed hierarchical chord-based architecture of MIIS servers. Currently, mobile wireless network mainly focuses on the design of ubiquitous access technology and improving network throughput. However, due to (1) increasing demand for ubiquitous access technology, and (2) the exponential growth of data traffic which triggers a fast escalation in the demand of energy, in our future work, energy efficient handover mechanism in heterogeneous networks will be one of our research directions.

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