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HANDOVER ARCHITECTURES FOR HETEROGENEOUS NETWORKS USING THE MEDIA INDEPENDENT INFORMATION HANDOVER (MIH)

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Abstract. In heterogeneous networks, network selection by nature is a multi-dimensional problem. Many parameters need to be considered for handover decision making. Apart from handover accuracy and efficiency, an important consideration is the scalability and signaling overhead of such handover algorithms. In this article we propose to break down a Simple Additive Weighting (SAW) based heterogeneous handover algorithm in two parts. The execution of the first part is carried out in an independent and proactive manner prior to the actual handover, assuming three different handover architectures. The handover architectures are differentiated based upon the level of the distribution of the handover algorithm among multiple network components. The Media Independent Handover (MIH) and its different services are used to retrieve and share information among MIH enabled nodes and for conformity among heterogeneous network standards. The proposed algorithm is evaluated with respect to handover accuracy, handover delay efficiency and signaling overhead. The evaluation is carried out for all three handover architectures using simulations. Only handovers between Wi-Fi (IEEE 802.11) and WiMAX (IEEE 802.16) networks are considered. But the handover framework is general and can be extended to consider other wireless and mobile communication networks.

Keywords: Handover efficiency, network selection, handover architectures, heterogeneous handovers, MIIS, MIH, heterogeneous networks

1 INTRODUCTION

Handover decisions in a heterogeneous network environment are complex in terms of their actual implementation. The complexity is due to the heterogeneity of the environment, Quality of Service (QoS) of different network media, and user needs. This means that handover decisions need to consider many factors and parameters to be general enough to handle most situations and at the same time to ensure individual user needs are fulfilled. Traditionally, handover algorithms have been proposed to be performed in their entirety on a single entity like a Mobile Node (MN) mostly in case of an open system and on a central server mostly in case of operator owned closed networks. Both these approaches might suffer from inefficient resource utilization on both the MN and the network. The former approach puts a lot of processing and signaling burden on the MN. Which is usually the most resource restricted network component in terms of processing power, battery power and memory. Moreover, a handover decision performed on the MN assumes that all the parameters considered for handover decision are also acquired by the MN itself through measurements or from the network; but, in reality, the number of measurable parameters might be limited and will also drain MN and network resources. Acquiring them from the network might not be possible as well, because operators might not feel comfortable sharing their network configuration parameters, traffic conditions, and specially handover decision criteria with the user in closed networks. Using the latter approach, if the handover decision is taken by a central entity (e.g. a central server) in the network. Then such a centralized architecture naturally reduces the scalability of the system. Moreover, additional efforts are required to keep dynamic handover parameters updated on the central server. Heterogeneous handover algorithms require extensive processing and interaction among multiple network components. The interaction among multiple network components is carried out for the much needed collaboration and cooperation of network components for accurate and efficient handover decisions; but such interactions will result in excess signaling overhead, resulting in scalability issues and wastage of precious network resources like bandwidth. Moreover, such interactions will also contribute to the overall signaling overhead in the network. Signaling storms are a big challenge in 3G and 4G networks and in the past have caused these networks to perform poorly or crash down [1]. Keeping this in mind the following requirements can be outlined for a handover algorithm in heterogeneous access networks.

1. The handover algorithm should consider a wide variety of network related and user related criteria for precise handover decisions and to be general enough to handle most situations.
2. The handover algorithm should ideally be scalable and should contribute as little as possible to the overall network signaling overhead.
3. The handover decision apart from being required to be precise and accurate also needs to be efficient in terms of handover latency, so that the QoS requirements of real time communication flows are fulfilled.
4. The handover parameters and decision criteria should ideally remain concealed from the user. This will also make the user preferences regarding network selection automatic and the users are no longer required to be technically knowledgeable to define their own network selection preferences.

One answer to the fulfill the above stated requirements might be to distribute handover algorithms among multiple network entities. For such an approach it is very critical that the handover decision is first broken down into sub parts. Then the sub parts are distributed among multiple network components for better scalability. Such a distribution might have multiple levels. For handover delay efficiency it is important to identify which sub parts of the algorithm can be performed pro-actively even before the handover, so that the handover delay is kept to a minimum without sacrificing accuracy and the number of considered parameters for handovers. Such a distribution is expected to result in efficient resource utilization, which will enable the consideration of more parameters to design general, robust and powerful handover decision algorithms. Considering more parameters also means that handover decisions can be tailored to each individual user applications QoS, contextual (e.g. location, speed) and preferential (e.g. service cost) needs.

This article is an extension to our earlier work in [2] in which we introduced and evaluated two handover architectures. In this article we introduce a third handover architecture and take the evaluation to the next level by considering signaling overhead of all three handover architectures. A simple but powerful handover algorithm based on Simple Additive Weighting (SAW) [3] is used as an example. The handover algorithm is first tailored to our needs and then implemented as a test case. Maximum number of network and user criteria is considered for handover decision making. The handover criteria and their exact relative importance used for handover decision remain concealed from the user, even though the primary control of the handover process still remains with the MN. The Media Independent

Information Handover (MIH) [4] and its facilities are utilized for intelligent handovers and interaction among network components. Two proposals are provided for distributing the processing burden of heterogeneous handovers across multiple network components and compared against a centralized approach. The comparison regarding both the number of control signaling overhead and its overhead volume is in bytes. The handover efficiency and accuracy of the proposed algorithm with different architectures is also evaluated.

This article has been arranged as follows: Section 2 contains related work, introduction to MIH and discussion on the importance of handover parameters. Section 3 provides details on our SAW algorithm, the three handover architectures and their associated signaling overhead. Simulation scenario and parameters details are provided in Section 4. A discussion on generated results is given in Section 5 and in Section 6 conclusions are drawn.

2 BACKGROUND

2.1 Related Work

Marsch et al. [5] discuss the challenges in future mobile communication networks. Mobility, session management, interference management and other aspects are considered. The authors stress that a hybrid form of centralized and de-centralized mobility management is needed.

Authors in [6] propose to combine Radio Resource Management (RRM) with handover execution and discuss three RRM architectures, namely centralized, distributed and hybrid. They conclude from their simulation results that a centralized approach provides better handover delay performance in high network load and that a distributed approach should only be used for moderate or low network load. [7] analyzes the signaling complexity of MIH in the presence of packet loss and its effect on handover delay performance. The authors validate their mathematical model with the help of simulation results. They conclude that there is a trade-off between handover latency and MIH signaling overhead. Ekici [8] studied the performance bounds of location management schemes in next generation wireless networks. Availability of complete and perfect knowledge about the network parameters, user mobility information, and connection patterns is assumed. Overall signaling costs for location management, location registration, and paging is estimated over the wireless medium.

A large number of Multiple Attribute Decision Making (MADM) handover algorithm proposals are present in the literature. Some of these proposals are discussed next. In [3] the author has proposed to use fuzzy logic to deal with imprecise handover criteria and user preference. After imprecise data are first converted to crisp numbers, classical MADM methods SAW and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) are applied. In [9] Grey Relational Analysis (GRA) is used to rank the candidate networks while Analytical Hierarchical Process (AHP) [10] is used for weighting the criteria. Multiplicative Exponent Weighting

(MEW) [11] is another MADM weighting method. In [12] the authors have provided a comparison of four algorithms, i.e. MEW, SAW, TOPSIS, and GRA. They show that MEW, SAW and TOPSIS have similar performance for the four considered different traffic classes, while GRA's performance is slightly better. In [13] the authors have provided a survey of different heterogeneous handover schemes. In [14] the authors have proposed to use AHP for weighting and TOPSIS for ranking in a WiMAX, Wi-Fi environment. [15] has proposed a fuzzy extension to AHP and an MADM method called ELECTRE is proposed for ranking. There are a number of other research papers published on heterogeneous handovers and a great variety of proposed algorithms exists. But most of these algorithms are based on different combination of SAW, MEW, GRA, ELECTRE and TOPSIS with AHP, fuzzy logic and neural networks, etc. Moreover, most of the above algorithms are proposed to be carried out in their entirety by a single entity, i.e. a central server or by an MN.

Distributed handover proposals are provided in [16, 17, 18] in which the rank calculation is delegated to the visiting networks. The scheme presented in [17] also accommodated call admission control into the algorithm. The scheme introduced in [16] was extended in [19] to consider only those candidate networks for handovers which provides a certain level of trust. However, all these schemes suggest that the proposed handover algorithms are carried out during handover execution with zero pro-activeness. This might result in high handover latency and scalability problems, especially if maximum number of handover parameters are being considered for handover decision. Also all these schemes consider very limited criteria (only three for the scheme in [16]) for handover decision making and user preference consideration is also limited, i.e. only service cost is considered in [16, 17, 18]. Therefore all these schemes are limited in their accuracy and generality. Moreover, these schemes require the MN to discover point of attachments by scanning which might result in high handover delay depending upon the number of detected BS's as no Media Independent Information Service (MIIS) is used. The scheme in [16] does not make use of MIH at all, while the scheme in [18] makes use of MIH but for merely exchanging messages between the MN and the BS's. Another problem is that the handover parameters and their relative importance weights used for handover decision making are assumed to be provided by the MN as part of its request to the visited networks. This might not be very practical as discussed earlier in our fourth handover requirement.

In contrast to these schemes, we consider handover criteria ranging from network traffic conditions to user preferences (both service types and cost). We propose to make use of intelligent services provided by MIIS for low latency handovers where no scanning for discovering 802.11 access points [20] is performed and the MIIS makes use of MN coordinates to return the information of only relevant BS's. In addition we also propose an MIIS based semi and fully distributed mechanisms. One other major difference between our scheme here and those in the literature is the pro-active ranking of base stations before the handover execution. We evaluate our schemes from two perspectives. One is the amount of signaling overhead generated to support the operations of a particular handover architecture assuming three different handover architectures. Second is to show that despite being distributed the efficiency and accuracy of algorithm for network selection is not adversely affected. For this purpose handover efficiency of the considered example algorithm is compared to an "802.11 Preferred" scheme assuming three handover algorithm distribution levels.

2.2 Media Independent Handover (MIH)

Media Independent Handover [4] is an IEEE standard which provides link layer intelligence and other network information to higher layers for optimized handovers between heterogeneous networks. The standard defines information that helps in network discovery and specifies the means by which such information can be obtained and be made available to the MIH users. Figure 1, taken from the MIH standards document [4] shows how the MIH Function (MIHF) is interfaced with other layers of the protocol stack in a multi face MN or network node. A single media independent interface MIH Service Access Point (MIH_SAP) is used to provide services to the MIH users. All interactions of the MIHF with the lower layers take place with the help of media-specific protocol instantiations of MIH_LINK_SAP. The purpose of the MIH standard is not to design a new protocol, but to complement the existing mobility management protocols in taking handover decisions. The MIHF provides three kinds of services to achieve this. A short description of these services is given next.

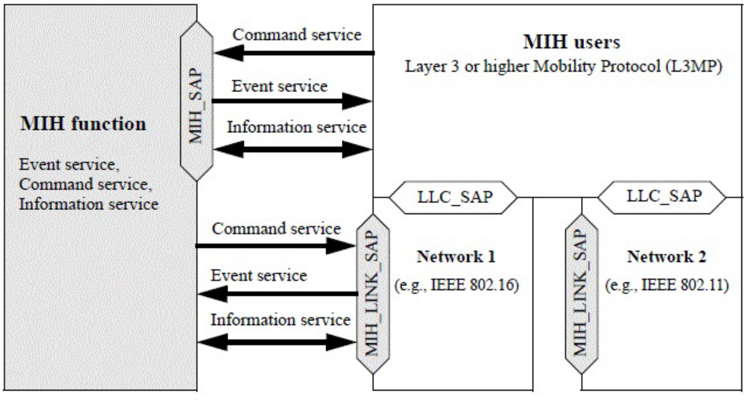

Figure 1. MIH services and their initiation

2.2.1 Media Independent Event Service (MIES)

Events are generated by lower layers to notify high layers of the status of physical, data link and logical link layers or predict state change of these layers. Events originate from the MIHF (MIH Events) or from a lower layer (Link Events) within the protocol stack of an MN (local events) or network node (remote events). The destination of an event is established with a subscription mechanism that enables an MN or network node to subscribe for a particular event.

2.2.2 Media Independent Information Service (MIIS)

The MIIS provides a framework and the corresponding mechanisms by which an MIHF (MN) entity can discover and obtain network information existing within a geographical area to facilitate network selection and handovers. MIH Information Service can be used to provide network information to the MIHF. The scope of these services may be local or remote. In case of remote services the MIH entity on the mobile communicates with an MIH entity in the network for these services. The network side of the MIH entity with which the MN exchanges MIH information is called Point of Service (PoS). The MIH standard supports both layer 2 and layer 3 transport option for information access.

2.2.3 Media Independent Command Service (MICS)

The higher layers can control the lower layers (physical and MAC) using MIH command service. The higher layers control the reconfiguration or selection of an appropriate link through a set of handover commands. When an MIHF receives a command it is always expected to execute it. Commands may be generated by MIH users (MIH Commands) or by MIHF itself (Link Commands). The destination of these commands may be local MIHF or lower layers (Local Commands) or remote MIHF (Remote Commands).

2.3 Importance of Handover Parameters in Heterogeneous Wireless Networks

As mentioned already, a heterogeneous handover algorithm needs to consider a wide variety of criteria or parameters to make efficient handover decisions. The criteria ranges from network related parameters (like delay, jitter, packet loss, available bandwidth, running application QoS requirements) to users preferences (such as service cost and context information such as speed and GPS coordinates). The importance of all the handover parameters is not the same for all handover cases and is determined by the user preferences and context, application QoS requirements and network conditions for any particular handover case. For example, a particular network can only be considered as a candidate network for handovers if it is physically available at the current physical location of the user, the user has a service subscription for this network and if it provides the MN required QoS. Similarly the relative importance of the handover parameters for handover decision making is not the same for all handover scenarios. The level of required QoS is usually determined by the nature of the service flows the user is running. For example a real time service like VoIP is more sensitive to delays and jitter than available bandwidth, while a non-real time service such as a file download is more sensitive to available bandwidth than delays and jitter. Potential candidate networks might also be decided by user service usage cost preferences. User speeds will also have an impact on the candidate network selection. For example a high speed user should not be handed over to small radio coverage networks like Wi-Fi. Because the new network connection time might be very small due to high user mobility and will result in unnecessary service disruptions [21]. This problems has been highlighted in the Figure 2 from our simulations which shows that the user connection time with Wi-Fi is decreasing with increasing mobility speed. Table 1 provides an example mapping the handover speeds to potential candidate networks for handovers.

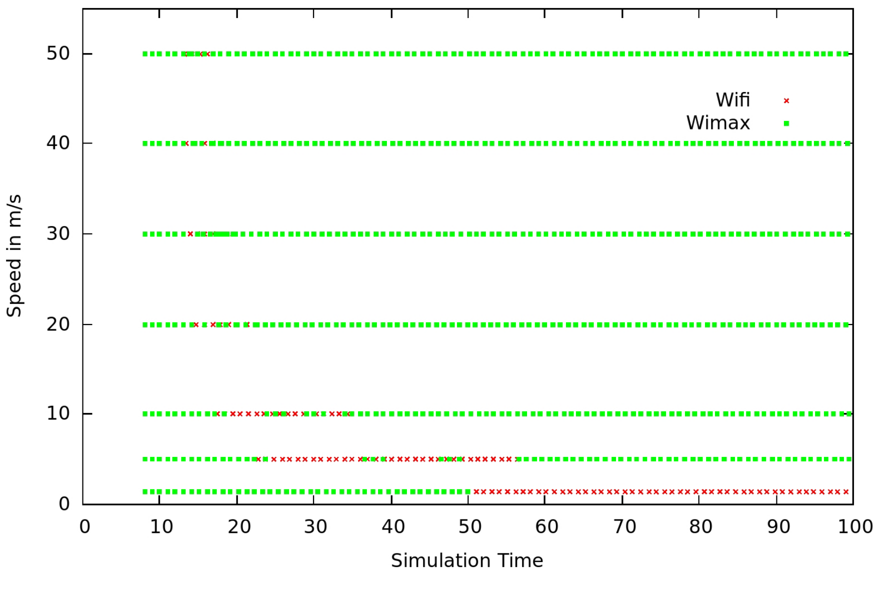

Figure 2. Mobility speed vs. network selection

3 PROPOSED HANDOVER FRAMEWORK

This section provides details of our example handover algorithm and the way it is carried out in the proposed three handover architectures, namely centralized, semi distributed and fully distributed. Details regarding the interaction between the different networks components such as between the MN, BS's and the MIIS are also provided here.

Mobility	Modes of transportation	Speed (km/h)	Areas	Candidate Networks
Low	Still, Walking	0–5	Homes, Offices, Public places	Wi-Fi, WiMAX, 3G
Moderate	Running, Cars, Bicycles	6–25	Urban Roads Streets	Wi-Fi, WiMAX, 3G
High	Cars, Trains, Buses	25–200	Highways, Motorways	WiMAX, 3G
Extreme	Trains, Planes	200–700	Airways, Motorways	3G, Satellite

Table 1. Possible candidate networks with respect to mobility speeds

3.1 Handover Algorithm

The handover algorithm considered in this article is based on Simple Additive Weighting (SAW). The main reason of opting for SAW is that despite being simple its efficiency and accuracy is still similar to other heterogeneous algorithms like MEW and GRA [12]. This article proposes to carry out the algorithm in two steps. In the first step referred to as the Initial Rank (IR), a QoS rank is calculated for each BS in the topology based on the network performance parameters, measured by each BS. This step is carried out in a proactive manner before the handover execution and the following equations are used for this purpose.

$$IR_{ik} = W_{bk}\frac{B.A_i}{B.T_i} + \frac{W_{jk}}{J_i} + \frac{W_{dk}}{D_i} + \frac{W_{lk}}{L_i}, \tag{1}$$

$$W_{bk} + W_{jk} + W_{dk} + W_{lk} = 1, \tag{2}$$

where IR_{ik} denotes the QoS rank of a particular BS_i for a particular service type k defined in the WiMAX standard and listed in Table 2. $B.A_i$ represents available bandwidth, $B.T_i$ represents total bandwidth, L_i represents packet loss, J_i represents packet jitter and D_i represents packet delays of a particular BS_i in the topology. W_{bk}, W_{jk}, W_{dk} and W_{lk} are the corresponding relative weights of bandwidth, packet loss, jitter and delay for service type k, listed in Table 2. UGS, rtPS, and ertps falls into real time services category while nrtPS and BE falls into non real time services category. The IR calculated in the first stage for all BS's does not include user preferences.

The IR pre-computed in Equation (1) is utilized in the second part of the algorithm to calculate the Final Rank (FR) of a BS considering specific user needs. The calculation of FR is carried out during handover preparation phase just before handover decision and execution. The handover decision is made based on this new revised rank and is computed with the help of the following equations.

Service Type (k)	W_b	W_j	W_d	W_l
Unsolicited Grant Service (UGS)	0.20	0.35	0.35	0.10
Real-Time Polling Service (rtPS)	0.30	0.30	0.30	0.10
Extended Real-Time Polling Service (ertps)	0.25	0.30	0.35	0.10
Non-Real-Time Polling Service (nrtPS)	0.70	0.10	0.10	0.10
Best Effort (BE)	0.70	0.10	0.10	0.10

Table 2. Considered service types and parameters weights

$$FR_{ik} = W_{QoS} * IR_{ik} + \frac{W_c}{C_i}, \tag{3}$$

$$W_{QoS} + W_c = 1, \tag{4}$$

where FR_{ik} represents the final rank or fitness score of a particular BS_i for a particular service type k. IR_{ik} is a pre calculated BS rank, W_{QoS} and W_c are the corresponding relative weights of QoS and cost of the connection. The value of these weights represents which parameter is more important for the user i.e. QoS or service cost. The user must have already specified about his/her service cost and QoS preference in the form of a Subscriber Level Agreement (SLA) with the operator. For simulation in this paper we have considered three SLA types listed in Table 3.

SLA Type	W_{QoS}	W_c	Description
SLA QoS	0.90	0.10	QoS most important & price least.
SLA Budget	0.70	0.30	A compromise between price & QoS.
SLA LowCost	0.10	0.90	QoS least important & price most.

Table 3. Considered SLA Types and parameters weights

3.2 Handover Architectures

This article proposes three handover architectures differentiated from each other with respect to the degree of distribution among multiple network components of the handover algorithm introduced in the previous section. The three handover architectures are introduced next.

3.2.1 Centralized Architecture

In a centralized architecture as indicated by its name both parts of the handover algorithm are carried out entirely on the central MIIS at different time instants. Centralized approach requires that all the BS's in the topology measure and update their handover parameters on the MIIS, where they are used for the computation of IR_{ik} and FR_{ik} separately. This can be achieved by sending handover parameter update messages to the MIIS from all BS's on a periodic basis for all the considered traffic types or classes. A similar approach of sending periodic messages to a central server for the purpose of Radio Resource Management (RRM) was also used in [6]. The parameters update messages are also sent when there is a significant change in the traffic conditions at the BS (i.e. a handover from/to the BS occurs). The MIIS on receiving such update messages from BS's, calculates IR_{ik} for all BS's in the topology using Equation (1) for all considered service types k and stores them locally for later use.

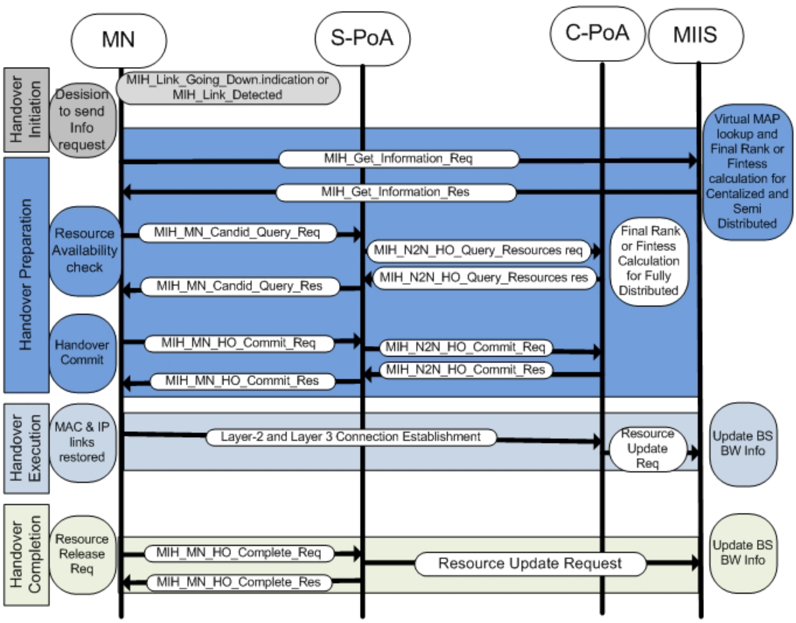

Figure 3. Proposed handover framework

Whenever an MN is using a WiMAX BS as source point of attachment (S-POA) and it detects the presence of an 802.11 network in an overlay topology as a candidate point of attachment (C-POA), it queries the MIIS server for network selection assistance as shown in Figure 3, providing its contextual information (i.e. GPS coordinates, speed), its SLA type and the active service type. The MIIS locates the MN on a virtual map with the help of the GPS coordinates of the MN and the surrounding BS's. As an alternative of using GPS coordinates for localization, the identity of the MN's current BS can also be used. After localization of the MN, the MIIS decides which 802.11 BS's are reachable to the MN at its current physical location. The MIIS then calculates the final rank FR_{ik} of all reachable BS's to this particular MN, using Equation (3). A BS with the maximum rank is identified and its information is returned to the MN. The MN after receiving this information checks if the received maximum rank is that of the currently connected BS/AP, if so it does not perform a handover otherwise a handover sequence is initiated to handover to a candidate BS/AP. For centralized approach the "Resource Availability Check" shown in Figure 3 is not performed and the MN goes directly into the "Handover Commit" phase. The purpose of "Resource Availability Check" phase is to confirm that the target network has enough resources. Since the candidate network suggested by MIIS is already the best one in the surrounding of the MN, such a check can be ignored. Even if the target network does not have enough resources for the new MN, the "Handover Commit Response" can be used by the target network to inform the MN of the lack of resources. An approximate number of control messages injected into the network to support the operations of such a centralized architecture, assuming no control packet loss and no re-transmissions, is given by the following equations.

$$I = \frac{\tau_f - \tau_i}{U.I} \qquad \text{for } 0<\tau_f>\tau_i \text{ and } U.I>0, \tag{5}$$

$$\zeta_{up} = I * \left(\sum_{k=1}^{N_{bs}} UP_k \right), \tag{6}$$

$$\zeta_{ho} = \sum_{j=1}^{N_{ho}} \left(Info_j + Comm_j + Comp_j + 2 * UP_j \right), \tag{7}$$

$$\zeta_{total} = \zeta_{ho} + \zeta_{up}, \tag{8}$$

where I is the number of times the fixed periodic update timer, i.e. $U.I$ (update interval) for sending updated parameters from BS's to MIIS, has expired in the time interval τ_i to τ_f. ζ_{up} represents the total signaling overhead due to the periodic update messages for I number of update expiries. UP_k represents the update parameter message of a particular BS k in the topology, N_{bs} represents the total number of BS's in the topology. ζ_{ho} represents the total signaling overhead due to exchange of handover messages for a total number of N_{ho} handovers. $Info_j, Comm_j, Comp_j$ are respectively the information, handover commit and handover complete query requests and replies for each handover j. UP_j represents update parameter messages for a particular handover number j. UP_j is sent by both the source and target BS's in particular handover to the MIIS server on each successful handover completion to reflect the current level of resources. The total signaling overhead is the sum of the signaling overhead due to periodic update messages and handover signaling, given by Equation (8).

3.2.2 Semi Distributed Architecture

The procedures in this approach are very similar to that of the centralized approach procedures, except that all BS's in the topology instead of sending their measured handover parameters, send their initial ranks, i.e. IR_{ik}, to the MIIS. Therefore in this case Equation (1) is executed on all BS's in a distributed manner and not on the

MIIS. Although in semi distributed approach the frequency of the update messages still remains the same as the centralized approach, semi distributed approach is expected to generate less signaling overhead. This is because the volume in bytes of parameter update messages, i.e. UP_k, for all the considered traffic classes in case of centralized is more than the volume in bytes of rank update messages, i.e. UR_k, for semi distributed. Moreover, since the first part of the algorithm, i.e. IR_{ik}, is executed on all BS's in the topology in a distributed manner, semi distributed approach will have better scalability. An approximate number of control messages injected into the network to support the operation of semi distributed architecture is given by the following equations.

$$\zeta_{up} = I * \left(\sum_{k=1}^{N_{bs}} UR_k \right), \tag{9}$$

$$\zeta_{ho} = \sum_{j=1}^{N_{ho}} \left(Info_j + Comm_j + Comp_j + 2 * UR_j \right), \tag{10}$$

where I is given by Equation (5). UR_k represents the update rank message sent by a particular BS_k in the topology both on a periodic basis and after each successful handover completion.

3.2.3 Fully Distributed Architecture

In a fully distributed approach each BS calculates its own rank IR_{ik} by Equation (1) as explained in the previous section. But these ranks are stored locally for later use and refreshed periodically, instead of being sent to the MIIS server. The MN as before on detection of an 802.11 network queries the MIIS. The MIIS this time makes use of the MN's GPS coordinates only and after identifying one or more reachable candidate BS's, returns their list to the MN. When the MN receives the candidate list it sends *MIH_MN_Candid_Query_Req* message(s) to all candidate BS's in the candidate list received from the MIIS. This operation is similar to the one defined in the MIH standard but the only addition here is the use of MN's GPS coordinates to refine the list of candidates PoA's on the MIIS. This list could also be further refined to meet further specific needs of an MN, e.g. the consideration of MN's speed in case of highly mobile users. The MN must also provide information regarding the service type it is running and its SLA type in *MIH_MN_Candid_Query_Req* message. All BS's receiving a *MIH_MN_Candid_Query_Req* message calculates their final rank FR_{ik} by Equation (3) which is then returned to the MN in the *MIH_MN_Candid_Query_Res* message of the MIH standard as shown in Figure 3. The MN after receiving responses from all candidate BS's identifies a BS with the maximum FR_{ik} and then initiates a handover to it. The amount of signaling overhead of fully distributed architecture in the number of messages is given by the following equations.

$$\zeta_{up} = 0, \tag{11}$$

$$\zeta_{ho} = \sum_{j=1}^{N_{ho}} \left(Info_i + \sum_{i=1}^{NC_j} Cand_i + Comm_j + Comp_j \right), \tag{12}$$

where NC represents the total number of candidates returned from the MIIS server to the MN during a particular handover j and $Cand_i$ represents the candidate query request and response messages exchanged between the MN and the candidate BS's.

4 SIMULATION SCENARIO AND PARAMETERS

The National Institute of Standards and Technology (NIST) has implemented the Media Independent Handover Function (MIHF) based on draft 3 of 802.21 standard in the form of an add-on module [22] for Network Simulator (ns-2) [23] version ns-2.29. The implementation supports both Media Independent Events Service (MIES) and Media Independent Command Service (MICS), but does not support the Media Independent Information Service (MIIS) [24]. We have used this implementation for our simulation and have added MIIS server functionality. NIST also integrated into their module an implementation of 802.11 [25] and 802.16 [26].

Figure 4 represents the topology of our simulation scenario. The simulation area was set to $3\,000 \times 3\,000\,\mathrm{m}^2$ and consisted of three 802.11 AP's and one WiMAX BS. At the start of the simulation the MN is stationary and is attached to the WiMAX BS. The correspondent node, i.e. CN_1, starts sending unicast Constant Bit Rate (CBR) traffic in the form of UDP packets to the MN at simulation time 10 sec. The UDP packets size was set to 1 000 bytes and used different traffic rates. Background traffic is generated by CN_2 sending CBR traffic to static nodes in the topology represented by dotted blue line in Figure 4. The MN after some time starts moving at a speed of 8m/s in the direction of AP_1. When the MN reaches the boundary of the AP_1 cell it receives neighbor advertisement messages from AP_1 and a *MIH_Link_Detected* event is generated. At this point the MN queries the MIIS server for assistance in network selection, as shown in Figure 3. As a response to its query, the MN receives the candidate BS ranks from the MIIS in semi distributed and centralized architectures. With fully distributed architecture the MN receives a candidate list from the MIIS and the BS ranks are received from all the BSS's in the candidate list. The MN, on the basis of these candidate BS ranks, decides on whether it should perform a handover or keep connected to the WiMAX BS. The MN continues its motion and if it has decided to use the Wi-Fi AP, i.e. AP_1, then a *MIH_Link_Going_Down* event is generated, when it is moving out of coverage of AP_1. The MN, while connected to AP_1, performs another MIIS query to get assistance on candidate network selection. After the MN receives the required response, it then either performs a horizontal handover to another 802.11 BS, i.e. AP_2, or a heterogeneous handover back to the

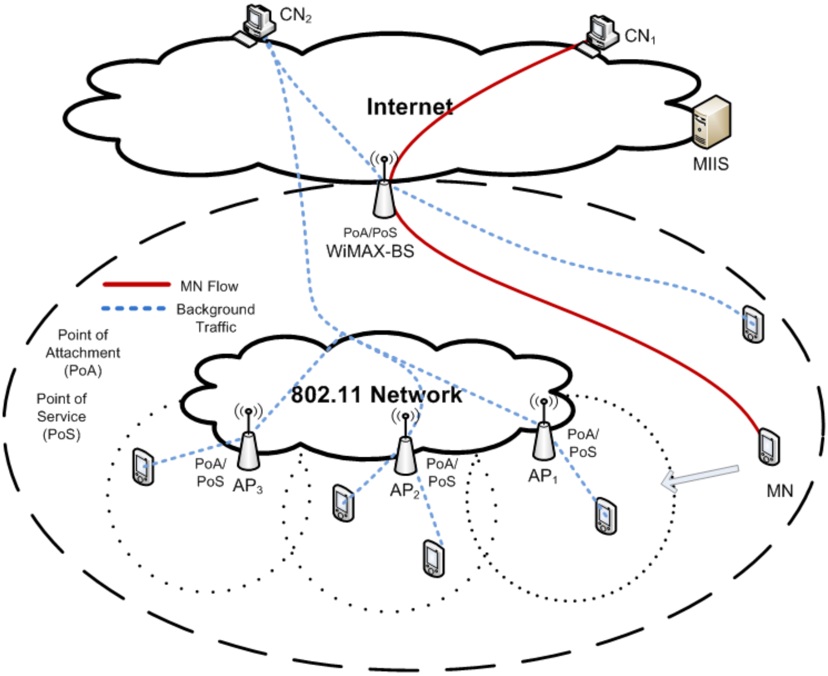

Figure 4. Simulation scenario

WiMAX BS depending upon their QoS ranks. When the MN is leaving the coverage of the last Wi-Fi BS, i.e. AP_3, only the WiMAX BS is returned as a candidate BS and therefore the MN handovers back to WiMAX.

5 DISCUSSION

5.1 Signaling Overhead

The signaling overhead given by the number of control messages for each of the three different handover architectures has been provided previously in Section 3 where they are introduced. This section provides cumulative signaling overhead comparisons of the centralized and the two distributed architectures in terms of the volume in bytes of control messages. The signaling overhead is formed by the control information sent by or received on a network entity, to support the operations of the proposed handover algorithm in the three handover architectures using MIH. The signaling overhead is computed using Equation (13) on three network entities, i.e. MN, MIIS and AP_1. The signaling overhead is calculated for a total of four handovers and simulation time duration $\tau_i = 10$ and $\tau_f = 105$ seconds. Estimating the signaling overhead generated by the handover algorithm to support its operations in each architecture type is helpful in estimating their scalability and efficiency. A quantitative comparison is given first followed by a qualitative comparison in the form of a summary table at the end of this section.

$$Overhead_{total} = Overhead_{total} + currentoverhead \tag{13}$$

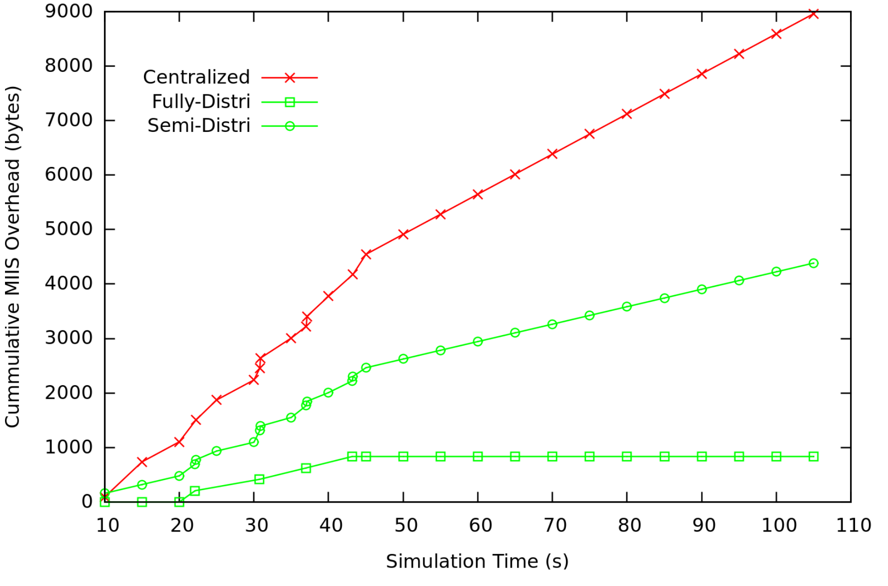

Figure 5. MIIS signaling overhead for the three architectures

Figure 5 shows the comparison of the three handover architectures with respect to commutative signaling overhead on the MIIS. From this figure it can be seen that the fully distributed approach outperforms the other two and generates the lowest amount of signaling overhead on the MIIS during the whole simulation period for a single MN. Moreover, for fully distributed approach the signaling overhead is only generated during handovers at simulation time 21, 31, 37 and 42 seconds when the MIIS is queried by the MN and remains constant otherwise. The semi distributed approach outperforms the centralized approach by 50 % due to the smaller size of rank update messages. The hike in the signaling overhead is also less steep when handovers are being performed. After the handover duration both of them show a linear increase of signaling overhead because of their periodic parameter and rank update messages required for their operation.

Figure 6 provides the comparison of the three architectures with respect to signaling overhead measured in the Cumulative number of bytes sent or received on AP_1. From this figure it can be seen that the fully distributed approach outperforms the other two and generates very little signaling overhead on AP_1 during the whole simulation period. The reason for this is that fully distributed approach

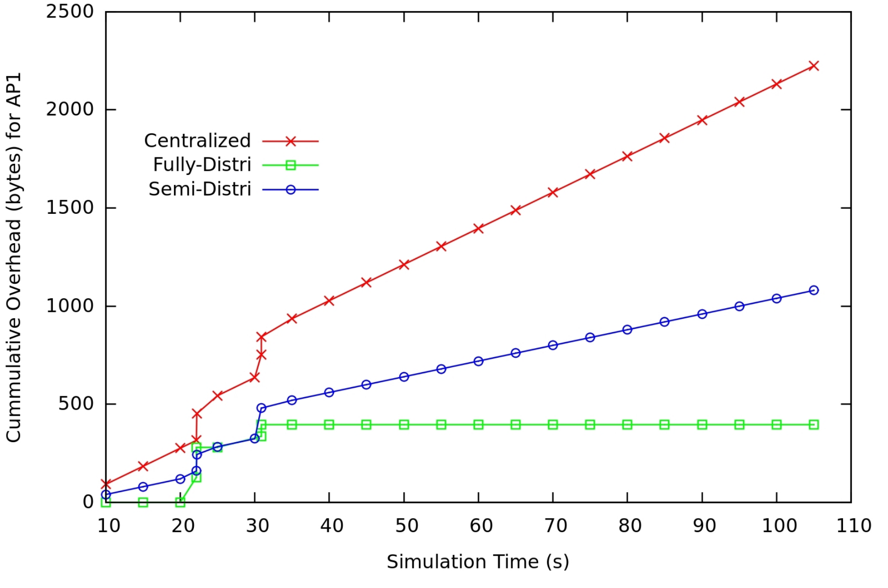

Figure 6. Cumulative signaling overhead at AP_1 for the three different architectures

generates handover signaling overhead only and no periodic update messages are sent. For fully distributed, the signaling overhead at AP_1 remains constant after the first handover at 23 secs when it acts as target AP for handover and the second handover at simulation time 30 seconds as source AP. Semi distributed performs second best; but its signaling overhead keeps growing linearly for the whole simulation period due to its periodic and after handovers rank update messages. Centralized approach performs the worst. Like semi distributed approach its signaling overhead grows linearly throughout the simulation duration, due its periodic parameter update messages. The signaling overhead shoots during handovers showing a steeper hike for centralized approach.

Figure 7 provides the comparison of the three architectures with respect to signaling overhead measured in the cumulative number of bytes sent or received on the MN. From this figure it can be seen that the semi distributed and centralized approaches perform exactly similar and their curves overlap. This is because the interaction of the MN with the network components (i.e. MIIS and BS's) in both the cases is exactly the same and the number of bytes sent/received is also the same. They only differ from each other in the signaling overhead generated due to periodic update messages to the MIIS from BS's as shown in Figure 5. Fully distributed approach performs the worst as it puts more burden on the MN in comparison to the semi and fully distributed approaches. The reason for this worst performance is that in case of fully distributed the MIIS returns more than one candidates to the MN in the candidate list. This results in additional interactions between the MN and the BS's in the candidate list resulting in comparatively high signaling overhead at the MN. Therefore the signaling overhead for the MN in this is a function of the number of potential candidates returned to the MN by the MIIS. In our simulation settings a maximum of two candidates were returned by the MIIS.

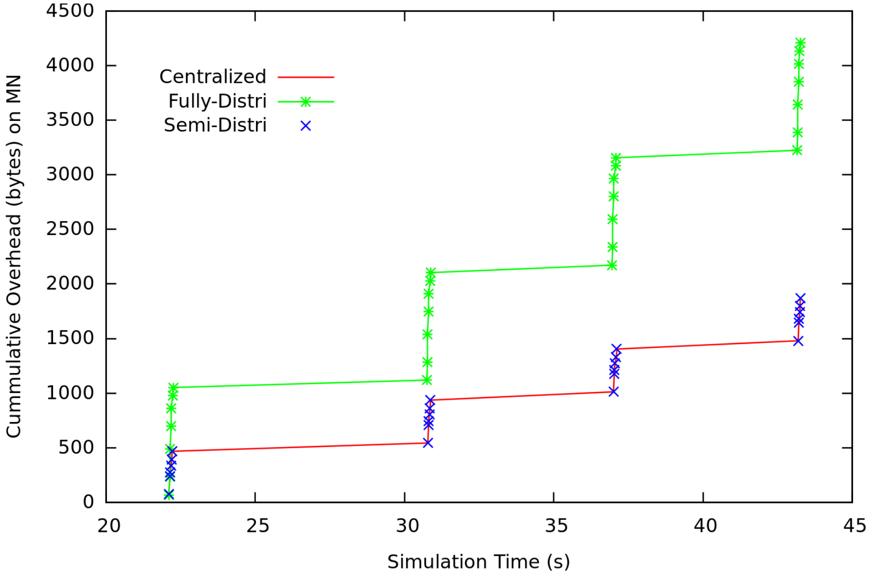

Figure 7. Cumulative signaling overhead on MN

The signaling overhead of the different architectures has been summarized in Table 4. From this table we can see that the centralized architecture generates the lowest possible signaling overhead on the MN, but its signaling overhead on the network side is high. The other extreme is the fully distributed case which generates lowest possible signaling overhead on the network side but high signaling overhead on the MN side. Semi distributed is a compromise between the two. Therefore semi distributed might be the most appropriate architecture for future networks. A similar conclusion was also drawn in [5] where the authors advocated the use of a hybrid form of centralized and distributed architectures. It should be noted, that only the fully distributed approach is fully in line with the MIH architecture and that this solution does not require a dynamic Media Independent Information Service.

5.2 Handover Accuracy and Efficiency

This section provides some insights on the results gathered from simulations from two important aspects. First aspect is that even after distribution the SAW based handover algorithm satisfies the user requirements. For this purpose the effect of

Architecture	Signaling Overhead at MN	BS	MIIS	Scalability	Dynamic MIIS Req
Centralized	low	high	high	low	yes
Semi Distributed	low	moderate	moderate	moderate	yes
Fully Distributed	high	low	low	high	no

Table 4. Signaling overhead comparison summary

different user related and network related parameters on network selection is evaluated. Second aspect is the handover delay performance comparisons of the three different handover architectures, to evaluate which architecture is the most appropriate for next generation networks. For this purpose the handover delay efficiency of the three handover architectures is compared to each other and to an 802.11 preferred scheme. The configuration of network traffic conditions was kept such that the WiMAX BS would be more favorable for real time applications and is assumed to offer low packet delays, low packet loss, and low packet jitter for a high service cost; but it also has high network utilization or load. On the other hand, as compared to WiMAX, Wi-Fi AP's have low network utilization and high packet delays, packet loss and jitter making them favorable for mostly non real time flows at low service cost. With such a configuration the target is to analyze if the user needs (QoS and service cost) are fulfilled by our SAW algorithm for network selection.

Figure 8 shows the effects on network selection, of different types of user services with the same SLA, i.e. SLA QoS. Since cost of the service is not an issue for this type of SLA, we can see from this figure that real time services UGS and rtPS favor the WiMAX BS even though Wi-Fi is detected. But for a non-real time service like BE, the MN makes full use of Wi-Fi coverage due to the fact that Wi-Fi AP's are lightly loaded (more chances of getting more bandwidth) in comparison with WiMAX. An important thing to note from this figure is that throughput is not as steady for the MN when using Wi-Fi, as it is when using WiMAX. The reason for this is frequent handovers due to small coverage area of 802.11 BS's. Throughput variation is only critical for real time flows and not so much for non-real time flows like BE. Also for highly mobile users their mobility speed needs to be considered to reduce frequent handovers to a low coverage network as discussed before in this article. Therefore we can say that our SAW algorithm performs well by choosing the most appropriate network type for the current running service type. It is important to note that the difference in maximum achievable throughput in this figure does not represent throughput gain, as we have used different rate sources for different service types to avoid overlapping of curves in the figure for better visibility, although throughput variation in each individual case is important to consider.

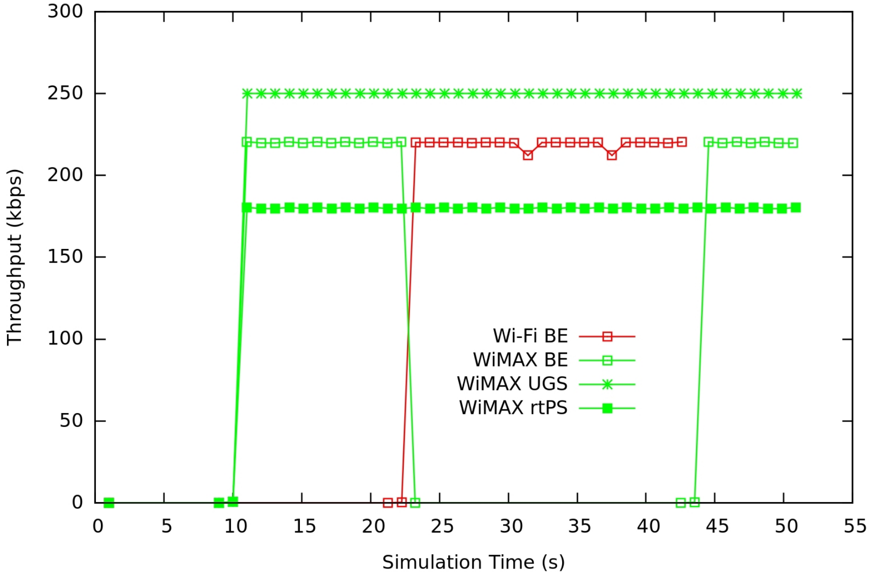

Figure 8. Network selection with the same SLA and different service types

Figure 9 shows the effect of different types of SLA's with the service type UGS, on network selection. The difference in maximum achievable throughput is not relevant but throughput variation in each individual case is relevant. From this figure with "SLA QoS" the MN never handovers to the Wi-Fi network and keeps on using WiMAX. At the other extreme is "SLA Lowcost" with which the MN makes full use of the Wi-Fi coverage. With "SLA Budget" the MN uses the Wi-Fi network but only if it offers a QoS of a certain level. In this case the rank of the last 802.11 AP, i.e. AP_3, turns out to be too bad and therefore the MN decides to handover back to the WiMAX network even though cheap Wi-Fi coverage is available. For this test case UGS is best served by WiMAX because of the nature of our assumed network configuration but the inclusion of service cost results in different network selection for different user preferences. We can easily conclude here that each MN gets a QoS level that is in accordance with the level of QoS specified in the service subscription of the user. Thus we can say that our SAW algorithm results in good user SLA satisfaction.

Figure 10 shows the handover performance comparison for the centralized scheme, the two distributed schemes and an "802.11 Preferred" scheme. The centralized and the two distributed schemes make use of MIH services and intelligent 802.11 scan mechanism proposed in our earlier work in [20]. In "802.11 Preferred" scheme an MN do not make use of MIH services and always prefers to handover to a Wi-Fi network whenever it is available without considering any other QoS criteria. Handovers with 802.11 preferred scheme do not make use of MIIS and therefore

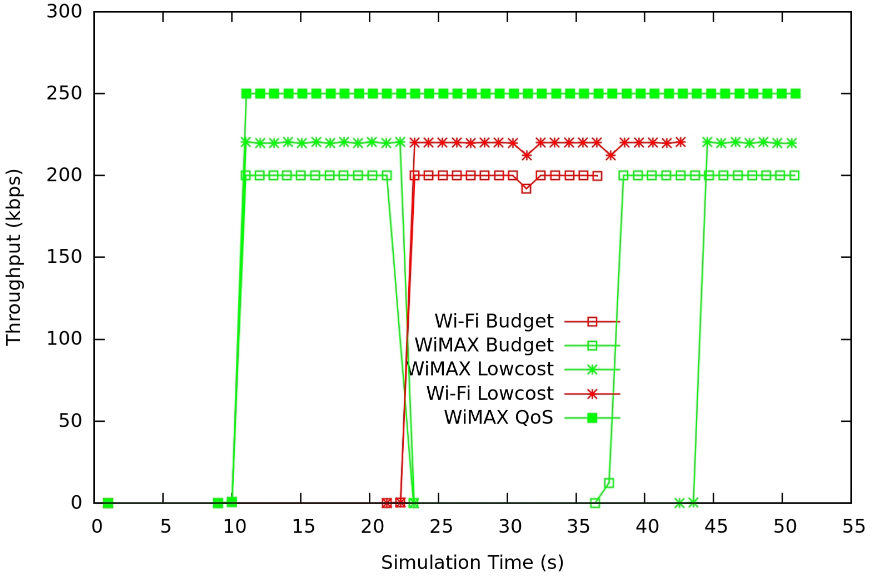

Figure 9. Network selection with the same service type and different SLA's

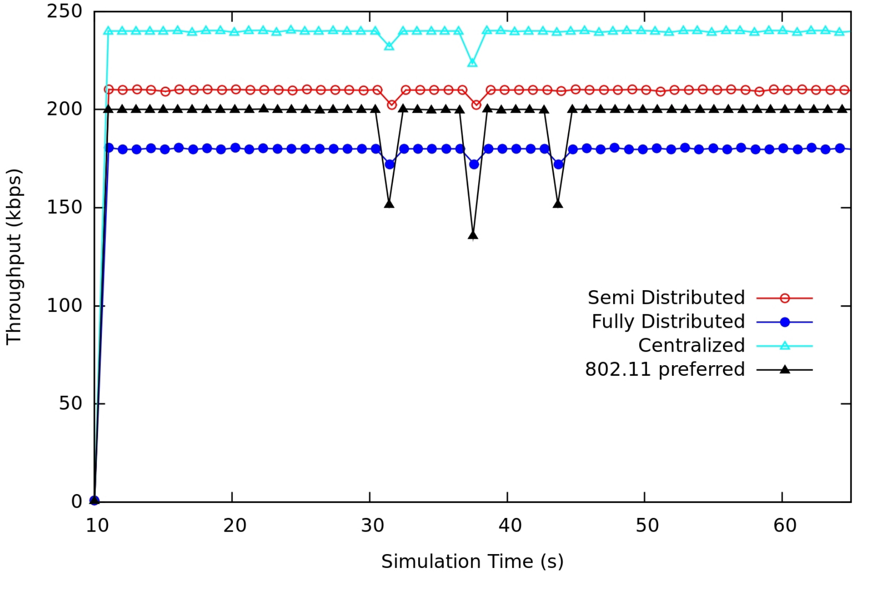

Figure 10. Handover performance comparison

standard 802.11 scanning procedures are carried out. The relative difference in the maximum achievable throughput in this figure is again not meaningful. But the throughput variation in the individual scheme performance is important to consider. We can see that using MIIS services for network selection along with a heterogeneous MADM algorithm can bring big advantages. This can be seen from the drop in throughput in the Figure 10 for "802.11 Preferred" scheme while in the same figure, the distributed and centralized SAW based schemes using MIH maintains a steady throughput. From handover performance point of view the two distributed methods perform very similar to each other. The handover delays recorded for the four handovers performed in one simulation run have been plotted in Figure 11 and summarized in Table 5. From both the figure and the table we can see that the three handover architectures do not differ a great deal from each other in terms of handover performance as the delays are measured in milliseconds. The variance in handover delays might be due to layer three handover delays when mobile IPv6 flow redirection packets are sent over the network [27].

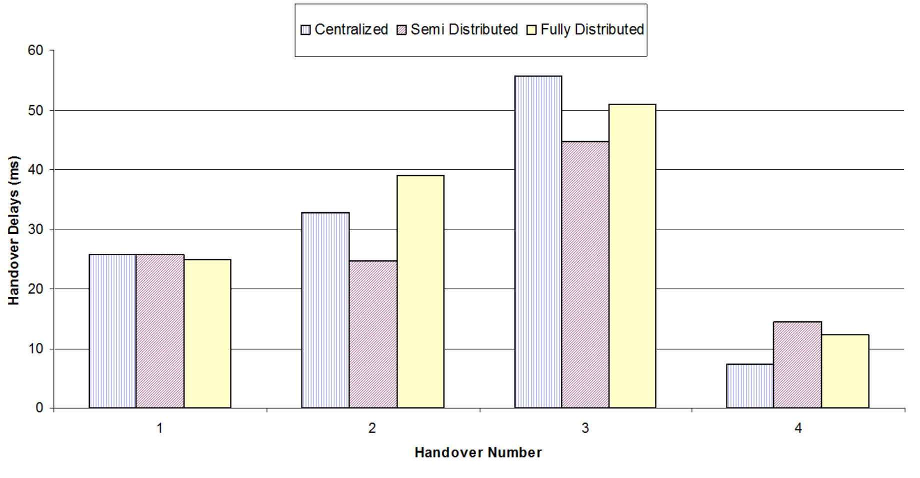

Figure 11. Handover delays (ms)

Handover	Centralized	Semi Distributed	Fully Distributed
1	25.75	25.75	24.87
2	32.83	24.78	39
3	55.7	44.64	51
4	7.38	14.48	12.31
Average	30.415	27.4125	31.795

Table 5. Handover delays (ms)

6 CONCLUSION

In this paper we have evaluated a SAW based MADM algorithm with respect to different distribution levels among multiple network components, with the help of services provided by MIH. Analysis of the proposed scheme is provided in terms of the signaling overhead generated to support its operations in three different handover architectures. Fully distributed approach generates high signaling overhead on the MN and low signaling overhead on the network side, while centralized architecture generates high signaling overhead on the network side and low signaling overhead on the MN. Semi distributed approach provides a compromise between the two extremes, as it distributes the signaling overhead between the MN's and the network side and provides better scalability than a fully centralized approach. Hence, it could be the preferred handover architecture for handover management in next generation networks. With the help of simulation results we have shown that a fully, semi distributed and centralized algorithms provide efficient handover mechanisms with good user satisfaction level for all the user service types and SLA types, but have different signaling overhead. Since distributed approaches have better scalability they allow more general, powerful and accurate heterogeneous algorithms to be implemented considering more parameters without sacrificing individual user needs. In terms of handover latency we have shown that despite being distributed at different levels the SAW mechanism with MIH performs efficiently and outperforms a simple "802.11 Preferred" strategy that does not make use of MIH services.

In the future this study might be extended to evaluate other heterogeneous handover algorithms like GRA, TOPSIS, ELECTRE etc. in a similar scenario to investigate if these algorithms can be used in a distributed manner at different levels. It may also be interesting to evaluate the kind of impact of the nature of different heterogeneous handover algorithms on signaling complexity of these algorithms in a heterogeneous network environment.

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