# An IEEE 802.21-based mobile-assisted vertical handover algorithm

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*Abstract*—**In the next generation wireless systems, heterogeneous access technologies will be intergraded in order to increase the efficiency of the whole system and improve the users' experience. However, achieving seamless service continuity when transitioning between heterogeneous networks is a difficult task. An approach to optimize these handover procedures through the introduction of a standardized framework is followed by the IEEE 802.21 working group. In this paper, we propose a mobile-assisted vertical handover mechanism which exploits the IEEE 802.21 framework and provides service continuity and increased system efficiency.**

*Index Terms*—**IEEE 802.21, vertical handover, policy-based algorithm, mobile-assisted handover.**

## I. Introduction

WIRELESS systems have developed rapidly during the last decade and became widely adopted. Thus, the need for sophisticated resource and mobility management mechanisms arose. Up to now, the existing systems operated autonomously and independently. However, current trends show that these networks will converge and closely cooperate with the Internet as well.

The wide-spread penetration of Wireless Local Area Networks (WLANs) and their ability to provide higher data rates compared with the traditional cellular systems, such GSM/GPRS, further boosted this trend. Thus, the two technologies are complementary: cellular systems provide high mobility but low data rates - while WLANs provide high data rates but low mobility. The convergence of these two worlds, created the so-called fourth generation (4G) systems.

However, there are many problems to overcome because of this convergence. One of the most important ones is to achieve service continuity when transitioning from one access network (AN) to another. In order to tackle this problem, handover control mechanisms have been introduced. A handover control mechanism is responsible to find the best possible AN to transfer the connections of a Mobile Node (MN) to - when the current AN is less desirable, for example because of poor link quality.

A plethora of solutions have been proposed by both the academic community and companies regarding handover management between heterogeneous networks (vertical handover). However, no standardization existed until March 2004 when IEEE created a group (IEEE 802.21) to investigate the aspects of vertical handover management and to propose a framework that provides service continuity with guaranteed Quality of Service (QoS) during a handover execution. In this paper, we exploit this framework and propose a vertical mobile-assisted handover algorithm that takes into consideration not only the network parameters, but user preferences as well.

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The remainder of the paper is organized as follows: Section II gives an overview of the 802.21 framework. In Section III related work is reviewed. Section IV presents the proposed mechanism and describes in details the functionality of the algorithms running on the MN and in the Core Network. Finally, in Section V we conclude our paper and give an outlook to future work.

## II. 802.21 Framework

As already mentioned, the IEEE 802.21 framework [1] is intended to provide the necessary mechanisms that facilitate seamless handover between heterogeneous IEEE 802 systems and between IEEE 802 systems and cellular systems (e.g. General Packet Radio Service (GPRS), Universal Mobile Telecommunications System (UMTS), and so on). A decision for vertical handover (handover between heterogeneous ANs) is not based only on signal quality metrics as in traditional horizontal handover (handover between same ANs). Several factors should be considered in the handover decision. Typically these include service continuity, user preferences, power management, security, quality of service and network availability.

The 802.21 framework provides the necessary functionality by exchanging network information that helps MNs determine the best available network to connect to. The core entity of its functionality is the Media Independent Handover Function (MIHF) which provides abstract services to higher layers through a unified interface. The communication with the lower layers of the mobility-management protocol stack is performed by technology-specific interfaces. The MIHF and its relationship with higher and lower layer protocol entities are depicted in Fig. 1.

MIHF defines three different services: Media Independent Event Service (MIES), Media Independent Command Service (MICS), and Media Independent Information Service (MIIS). These services are described in the following subsections.

### A. Media Independent Event Service

The Media Independent Event Service (MIES) provides services to the upper layers by reporting events corresponding to dynamic changes in link characteristics, link status, and link quality. These events can be either local or remote. Local events originate from the MIHF or any lower layer within the protocol stack of an MN whereas remote events take place in

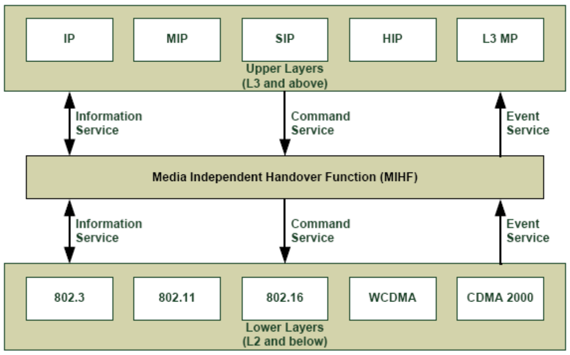


Fig. 1. Media Independent Handover Services

a network node. The destination of an event may be either the MIHF or any upper layer entity. Notice, that in order to receive an event notification, a subscription to this event should first take place. Specifically, an MIH entity registers to the lower layers for a specific set of events and gets notified when these events take place. In case of local events, messages usually propagate from the lower layers to the MIHF and from the MIHF to the upper layers. In case of remote events, messages propagate from the MIHF in one protocol stack to the MIHF in a remote protocol stack. Upon an event notification, the MICS is used to control the link behavior.

### *B. Media Independent Command Service*

The Media Independent Command Service (MICS) enables the upper layers to manage and control the functions of the lower (physical, data link, and logical link) layers related to handovers and mobility. MIH commands can be used either to gather information about the active links or to execute higher layer decisions regarding mobility to the lower layers. MIH commands are mandatory and should be always executed. A command can be either local or remote in the sense that the recipient may be located within the protocol stack that originated the command, or within a remote protocol stack. A command to scan for newly available links or to switch between available links are typical examples of MIH commands.

### *C. Media Independent Information Service*

The Media Independent Information Service (MIIS) provides information about the characteristics and services of the serving and neighboring networks while an MN moves. This information is used to optimize the handover decision and increase the efficiency of the system. Specific information elements and the necessary query-response mechanisms are defined in the context of MIIS. MIIS typically provides static link layer parameters such as the names and providers of the neighboring networks, channel information, MAC address and security information. However, dynamic information can be provided as well. This information can be available either through lower layers or upper layers. Information exchange through upper layers takes place if the information of the lower layers is not enough in order to make an efficient and optimized handover decision. For the representation of this information, existing standards such as eXternal Markup Language (XML) and Type-Length-Value (TLV) can be used.

## III. Related Work

A lot of research is currently being conducted on different aspects of the IEEE 802.21 framework. Melia, et al. [2] investigated the impact of signaling timing on network controlled handovers execution and performance and showed that Layer-2 related events reports should be split from Layer-3 handover procedures. The impact of terminal speed on the handover performance is investigated in [3]. Through simulations, the optimal thresholds in order to achieve zero packet loss within a handover execution were determined.

An analysis on the performance of the Mobile IPv6 (MIPv6) and Fast Mobile IPv6 (FMIPv6) for fast handover support in future heterogeneous networks has been performed in [4]. The results indicate that cooperation is needed between upper and lower layers in order to achieve fast handover operations and service continuity. In [5] a new set of MIH primitives and parameters is introduced in order to reduce handover latency when either MIPv6 or FMIPv6 is used. Specifically, when the proposed algorithm is applied to MIPv6, the router discovery time is eliminated and the total handover latency is reduced. In the case of FMIPv6, the probability that FMIPv6 can be performed in predictive mode is increased and the handover initiation time is reduced.

Dutta, et al. propose an integration between a Media-independent Pre-Authentication (MPA) [6] mechanism and the IEEE 802.21 framework in order to improve the handover performance and the security of the system [7]. Another approach to enable internetworking between WLAN and WMAN (Wireless Metropolitan Access Networks) based on the IEEE 802.21 framework is followed in [8]. This framework is designed to support mobile-controlled handover and defines the four following new entities as additions to the existing IEEE 802.21 framework:

- Network Selector Policy Engine (NSPE), which provides the core functionality of the whole architecture and makes the decisions for handover.
- Handoff Monitor, which detects the quality of the current link and reports its status to NSPE.
- QoS Adaptation, which performs an adaptation as soon as it received an adaptation request from the NSPE.
- Information Base, which stores all the information elements supported by MIIS. Additional information regarding the user's profile, network operator's policies and so on, is stored in the Information Base as well.

Li, et al. [9] propose a multi-layer integrated approach to achieve seamless soft handover in mobile ad hoc networks. Because the handover procedure affects all the different layers of the protocol stack, they stated that a cross-layer approach should be adopted. This is achieved by the introduction of various *managers* (software modules) that reside on different layers and exchange information in order to achieve service continuity during the handover procedure.

Finally, an architecture for a Universal Information Service on top of the the existing IEEE 802.21 framework, is proposed by Dannewitz, et al. in [10]. The purpose is to provide all the necessary information regarding the existing ANs, the available services, and the current usage context, so as to enable MNs take the optimum handover decision.

## IV. Vertical Handover Algorithm

In this section, we present our proposed mobile-assisted algorithm for vertical handover based on the IEEE 802.21 framework. This approach is based on the architecture proposed by Makris and Papazafeiropoulos in [11]. This solution introduced a Common Radio Resource Management (CRRM) mechanism in order to combine the respective mechanisms of the different heterogeneous networks and provide all the necessary information for an optimal handover decision. In our current approach, we exploit the IEEE 802.21 framework, thus there is no need for CRRM functionality. However, the IEEE 802.21 framework needs to be extended in order to support our proposed architecture. The new functional entities added to the initial IEEE 802.21 framework are depicted in Fig. 2, and described as follows:

- ***Handover Module:*** It provides the core functionality of our proposed solution. At the MN, the MN algorithm is executed after a trigger has been received through the Handover Monitor element. It uses information stored in the Information Base of the MN. The outcome of the processing is sent to the MIHF of the Core Network.
- ***Handover Monitor:*** The proposed vertical handover algorithm is executed when the MN either detects severe deterioration in the received signal strength or a new AN becomes reachable by the MN. The Handover Monitor is responsible for detecting these events and reporting them to the Handover Module. This procedure is performed through the MIES of the IEEE 802.21 framework. Recall that based on the existing framework, an initial subscription to an event is needed in order for a report to be sent, if this event is triggered. For the signal strength deterioration report, the *MIH_Link_Parameters_Report* (defined in [1]) event is used. No message for the detection of a new AN event is defined in the existing standard. Thus, we introduce the *MIH_New_AN_Available* message which notifies the MIH entity that receives it that a new AN is available and a handover decision procedure should be initiated.
- ***Information Base:*** The information base exists both in the MN and one in the network side. In the MN, it stores information about the service profile, the user's profile, and the MN's profile. This information can be either stored permanently in the base, or acquired on demand. At the network, the information base stores information about the network operator's policies, the status of the network (e.g. network load), and the network topology. The information inside the Information Base is used by the Handover Modules (in the MN and in the Core Network) to make an optimum handover decision. Notice that the information base is introduced in order to store information obtained either from other MIIS resident in the same network or in the exterior or from the broadcast messages sent by neighbor networks. In addition, it stores information that are not currently supported by the MIIS specified in the IEEE 802.21 framework.
- ***Velocity and Position Estimator:*** This estimator is responsible for performing measurements in order to estimate the velocity (speed and direction) and the position of the MN. This information is used by the Handover Module in the Core Network for the decision making procedure (see section IV-A). The exact method to obtain this information is out of the scope of this paper. Any known technology such as Global Positioning System (GPS) or Universal Terrestrial Access Network (UTRAN) mechanisms for User Equipment (UE) positioning [12] can be used.

Two novel characteristics are introduced in our proposal. First, each active connection of the MN is handled separately when a handover needs to be executed. As it will be described in section IV-A, a prerequisite for this functionality is that the MN must be multimode [13]. Second, the proposed algorithm is split into two distinct and cooperating parts. The first runs on the MN and the second in the Core Network. The exact entity of the Core Network is not specified, but from the analysis performed in [11], the Serving Radio Network Controller (SRNC) [14] appears to be the most appropriate solution.

In the following subsections we explain the main assumptions about the network this algorithm was designed for, then we give a detailed description of the algorithm both in the MN as well as on the network side.

### A. Assumptions

As mentioned above, in our proposal we assume that the MNs can be multimode, i.e. they have multiple radio interfaces in order to support connections in parallel via more than one wireless access technology. This assumption extends the existing IEEE 802.21 framework which only requires the MNs to be able to support multiple-link layer technologies. In this approach, we focus on the problem of selecting the most suitable AN, when a new alternative access network becomes reachable by a MN with active connections (e.g. a voice call).

When a new AN becomes available, it is important to re-evaluate all active connections in order to achieve increased efficiency (in terms of resources distribution) of the whole system (i.e. multiple networks system that may or may not belong to the same operator). Since several parameters need to be taken into consideration, the decision process needs more time compared to the horizontal handover case in which, typically, only signal quality measurements take place. However, this proposal aims to increase the whole system efficiency in terms of defined policies, and not to handle situations of forced handovers due to poor signal quality. Thus, time restrictions are not of critical importance in this case. In the case of forced handovers, a simplified version of the algorithm that considers only signal quality and load balancing issues, is executed.

The capability of the network to calculate the position and the velocity of the MNs is another requirement of the proposed architecture. As mentioned above, the Velocity and Position

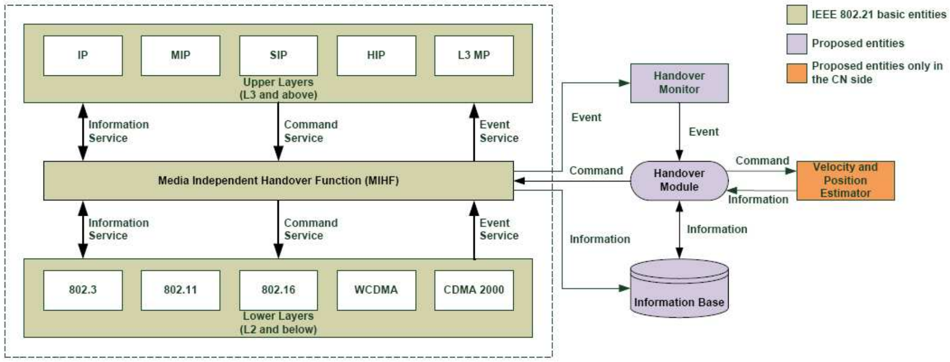


Fig. 2. Modified IEEE 802.21 framework

Estimator is responsible for providing this information to the Handover Module in the Core Network.

When deciding a vertical handover, the algorithm evaluates the following five parameters:

1) *Service profile:* Each service, even if it is adaptive to the bandwidth and QoS offered by each AN, has some minimum requirements (e.g. bit-error rate, jitter, etc.) on the link in order for this service to be successfully supported. If these requirements cannot be fulfilled, either the connections supporting this service are not handed over to the new AN or they are dropped.
2) *MN profile:* Each MN has different characteristics and capabilities. It has a particular set of radio interfaces, each with different requirements in terms of battery consumption, CPU power, available memory, and so on. In addition, the remaining battery and power consumption rate are not constant, but may depend on the type and number of active connections, current service demands, and the reachable ANs.
3) *Users profile:* The typical user is not interested in the network technologies that are available nor in the underlying difficulties to support seamless mobility and service continuity. The user simply wants to use certain services easily, with a given quality, and at the lowest possible price. Thus, the user should be able to prioritize their preferences in a simple and comprehensive way. Then, the available ANs should be prioritized based on the user's preferences. For example, if the user considers that minimizing cost is the highest priority, then the access network with the lowest cost should have the highest priority. If more than one ANs has the same cost, then the next user preference will be considered to decide and so on.
4) *Network operator policies:* Network operators want to control and balance the load of their whole system and to maximize their revenues if possible. However, they should consider their users' preferences in the decision process in order to increase the users' satisfaction.
5) *The MN's location and velocity information:* The availability and the accuracy of this information is critical for the handover decision process, because it can avoid the execution of unnecessary handovers.

All the above makes it quite clear that the selection of the radio interface to support handover has to be based on several preferences and requirements, some of them which may conflict with others. For example a user would prefer to pay the lowest price without sacrificing the quality of the received service. So, this selection requires a trade-off between the user's preferences and the operator's preferences.

As mentioned in section IV, the algorithm proposed here is split in two parts. The first part runs in the MN while the second one runs in the Core Network. This approach has two important advantages. First, the core network load for making measurements and performing calculations is decreased, as part of the calculations are performed in the MN. Second, the signalling exchange between terminals and network components is minimized. In the next two subsections, we present these two parts of the algorithm.

### B. Mobile Node Algorithm

The part of the algorithm running in the MN aims to prioritize the ANs for each connection separately. The result of this processing is sent to the Core Network in which the final decision is taken. Here, we assume that the system is fair, thus the Core Network will actually consider the MN's proposal. In this part of the algorithm, only the first three of the parameters mentioned in the previous subsection are considered; the service profile, the MN's profile, and the user's profile. The remaining two parameters are considered in the part of the algorithm running in the Core Network.

As an example, let us consider a user having two active connections. The first one is a voice call and it is served through a UMTS network, while the second one is a file transfer and it is served by a WLAN. Although it is not the best possible distribution of the active connections to the interfaces of the MN because of the high battery consumption, this example helps us present the functionality of our proposal.

If the user moves out of the coverage area of that particular WLAN and has only UMTS coverage, there are two options: either the WLAN connection will be handed over to UMTS or it will be rejected. In both cases the UMTS voice call is not affected. If the UMTS network operator has a considerably higher charge for UMTS compared to WLAN, then the user may prefer to postpone the file transfer until they have WLAN

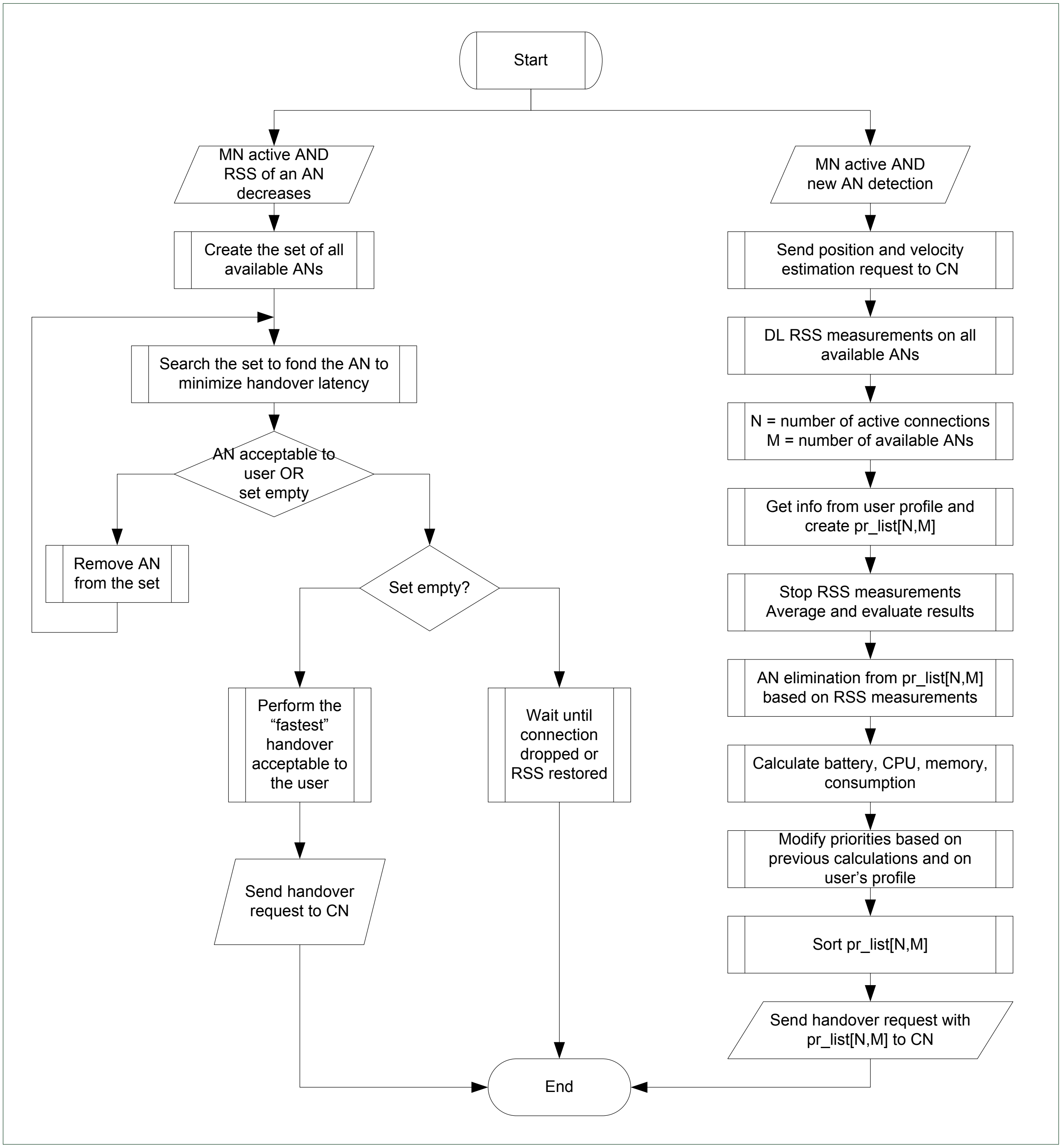


Fig. 3. Algorithm running in the mobile node

coverage available again. In this case, the service profile for the file transfer service indicates that low cost is more important than constant connectivity. Thus, this connection should not be handed over to UMTS. However, in our example, we consider a different service profile based on which, a handover from the WLAN to UMTS occurs in the case of poor signal quality.

The algorithm running in the MN is depicted in Fig. 3. As mentioned in section IV, the whole procedure will be initiated when one of two specified events is triggered. The first event is a signal quality measurement indicating that a severe deterioration of signal strength has occurred. Thus, an “urgent” handover, in terms of time constraints, is imminent. The second trigger is the discovery of a new alternative AN with adequate radio signal strength (RSS).

In the “urgent” handover case, the MN has at least one active connection and the RSS measurements indicate that the link quality has fallen below some specified threshold. In this case, the handover latency becomes the most critical factor in order to achieve service continuity. Thus, no evaluation of the different parameters is performed, since this, along with the signalling introduced, increases the time required for handover execution. Consequently, the handover type providing the least latency is chosen as long as it is acceptable based on the user's profile and the service profile.

This procedure is presented in the left part of Fig. 3. When the MN realizes (through the IEEE 802.21 MIES) that an "urgent" HO is imminent, it creates a set of all the alternative ANs that can support its connections. Then, it identifies, within this set, the AN that minimizes the handover latency. Notice that according to the available ANs and the architecture of the whole heterogeneous network, the outcome of the selection process varies. After discovering the AN with the minimum handover latency, the MN checks if this is an acceptable option according to the user's preferences. If it is acceptable, a handover request message (*MIH_MN_HO_Candidate_Query.request* [1]) is send to the Core Network to initiate a handover to this AN. Otherwise, the algorithm continues with the next AN, until either one AN acceptable to the user is found, or there are no more ANs in the set. In the latter case, no handover is performed and the connection may be terminated or normally continued in case that the RSS is restored back to acceptable levels.

The second trigger is the discovery of a new alternative AN in the proximity of the MN, while there are active connections. If the RSS measurements indicate that this new AN has acceptable signal strength and at least one connection is active, then the MN will create a list indicating the priorities of each AN for each specific connection. First, the MIHF in the MN will send a message to the MIHF in the Core Network in order to start performing measurements so as to estimate the position and the velocity of the MN. This message is necessary as we want the Core Network to avoid performing such measurements continuously, because they introduce considerable overhead over the radio interface. This message also contains the list of Base Stations that the MN receives acceptable signal strength. In order to enhance the existing IEEE 802.21 framework with this functionality, we introduce a new message in the MICS, called *MIH_MN_Position_Estimation.request*.

If $N$ is the number of active connections and $M$ the number of available ANs, then this priority list takes the form of a two-dimensional matrix $NxM$, named *pr_list* in Fig. 3. Then the MN reads the user's profile and according to the users preferences it constructs this matrix by assigning a value to each cell $(i, j)$ representing the priority of the $j - th$ AN for the $i - th$ connection. As an example, we consider a MN with $N = 3$ and $M = 3$. In this case, the priority list, based on a hypothetical user profile, is shown in Table I. For connection 1, *AN-1* has the highest priority, whereas *AN-2* the lowest. For connection 2, *AN-3* is set to zero, indicating that for this type of service this type of access technology is not acceptable to the user, for reasons such as monetary cost or QoS offered.

The next steps in the algorithm are to get all measurements performed in the downlink, then average and evaluate them. The evaluation results may indicate that a certain AN cannot fulfil all the constraints that a specific type of service requires, such as bit-error rate or jitter. In such a case, this AN will be eliminated from the priority list, by putting the value of zero in the specific cell of the *pr_list*. In the previous example, if *AN-1* does not fulfil the requirements of connection 1, the list will become as shown in Table II.

TABLE I
PRIORITY LIST AFTER CONSIDERING USER'S PROFILE

| | AN-1 | AN-2 | AN-3 |
|---|---|---|---|
| Connection 1 | 3 | 1 | 2 |
| Connection 2 | 1 | 2 | 0 |
| Connection 3 | 2 | 1 | 3 |

TABLE II
PRIORITY LIST AFTER AN ELIMINATION

| | AN-1 | AN-2 | AN-3 |
|---|---|---|---|
| Connection 1 | 0 | 1 | 2 |
| Connection 2 | 1 | 2 | 0 |
| Connection 3 | 2 | 1 | 3 |

Next, after the distribution of the connections to particular ANs, the algorithm estimates the CPU and memory requirements, the battery consumption, and all other factors that reflect the cost of the AN selection to the MNs characteristics. This estimate is combined with the user preferences and the *pr_list* is modified accordingly. In our example, we assume that the user wants to maximize the duration of the terminal's battery. This could mean that all connections should be supported by *AN-2*. The list will be modified, by finding the AN with the maximum priority for each connection and add it to the respective priority of *AN-2*. The result is presented in Table III.

TABLE III
PRIORITY LIST

| | AN-1 | AN-2 | AN-3 |
|---|---|---|---|
| Connection 1 | 0 | 3 | 2 |
| Connection 2 | 1 | 4 | 0 |
| Connection 3 | 2 | 4 | 3 |

The final step of the algorithm running in the MN is to sort the matrix per connection, in descending order, as far as priorities are concerned. The outcome of this process is the final format of the *pr_list*, which for our example is depicted in Table IV. So, for connection 1 there are two alternative ANs, *AN-2* and *AN-3*, with *AN-2* having the highest priority. Connection 2 has again two ANs, while connection 3 has three. These are in descending order of priority, *AN-2*, *AN-3*, and *AN-1*.

TABLE IV
SORTED PRIORITY LIST

| | | | |
|---|---|---|---|
| Connection 1 | AN-2 | AN-3 | |
| Connection 2 | AN-2 | AN-1 | |
| Connection 3 | AN-2 | AN-3 | AN-1 |

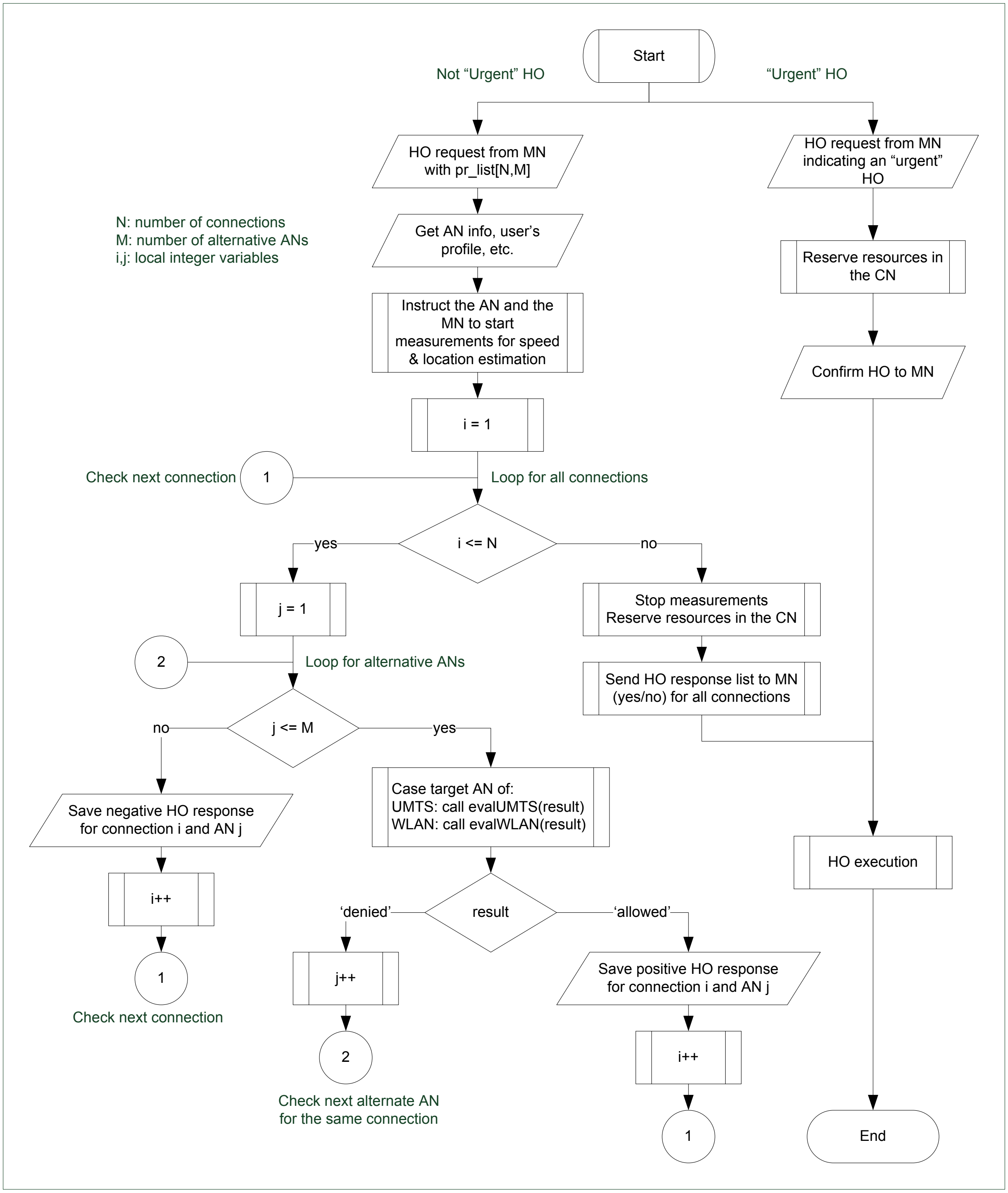


Fig. 4. Algorithm running in the core network

This is the final priority list sent to the Core Network. The *MIH_MN_HO_Candidate_Query request* message of the IEEE 802.21 MICS [1] can be used to transfer this information. However, its format should be modified in order to be able to support this new information. This priority list will be used as input to the algorithm executed in the Core Network which makes the final decision. This process is described in the following subsection.

### *C. Core Network Algorithm*

In this paper we have focused on mobile assisted handover, so the final handover decision is made in the Core Network. It is based on the last two parameters mentioned in subsection IV-A and on the *pr_list* constructed during the execution of the corresponding part of the algorithm at the MN. Thus, it is based on the policies of the operator and on velocity and position of the MN. Of course, uplink radio channel measurements indicating the quality of the uplink are also taken into consideration as in any handover case. Finally, AN specific parameters, such as the channel (WLANs) and/or codes (UMTS) availability are considered as well. Because many of these parameters change dynamically, the core network has to acquire updated information either periodically, or after certain events and message exchanging.

This part of the algorithm is depicted in Fig. 4 and it is executed when there is a request for a handover from a MN. As mentioned in section IV-B, a handover request can be either "urgent", i.e., due to radio signal strength degradation, or initiated to better support the existing connections. The latter is the outcome of the fact that there is a change in the number of ANs that the MN can reliably communicate with. Both of them are indicated by a handover request message from the MN to the Core Network.

First, we consider the case of the "urgent" handover which is presented in the right part of Fig. 4. The MN sends a handover request message to the Core Network indicating a handover initiation due to radio link degradation along with the target AN decided by the MN algorithm. This decision was based on the architecture of the heterogeneous network and it is described in the previous section. Then, the Core Network is responsible to reserve the appropriate resources for the handover execution and inform the MN about it. A modified version of the *MIH_MN_HO_Candidate_Query response* message of the IEEE 802.21 MICS is sent from the MIHF of the responsible Core Network entity to the MIHF entity of the MN.

In the case of a handover request due to a new AN detection from the MN, the time constraints are not so tight as in the "urgent" handover case. Thus, there is enough time to evaluate both network and user related parameters in order to take the optimum decision. This is depicted in the left part of Fig. 4.

First, the Core Network receives the handover request message including the AN priority list, which was the outcome of the part of the algorithm executed in the MN. Then, it gets all information related to the handover for all the involved ANs, such as the coverage area, the location of the access points or base stations the MN communicates with, and the user profile.

Next, the procedures to estimate the velocity and the position of the MN are initiated. This information is important in a heterogeneous network, since it influences the vertical handover decision. Consider that in some cases a handover to a different AN would be inefficient because of high speed, direction of movement, and location of the MN, or small coverage areas of the targeted AN. In such a case, the MN will reside in the targeted AN coverage for a very short time, and then another "urgent" (this time) handover will be necessary.

As an example, we can consider a heterogeneous network that includes UMTS cells (large coverage areas) and WLAN hotspots (small coverage areas). In such a case, when an MN moves into the coverage of WLAN and the MN indicates that for some connections WLAN is the preferred AN, a vertical handover from UMTS to WLAN is imminent. But, if the MN is moving very fast or at the border of the WLAN coverage area, then the Core Network has to deny such a handover, since in a very short time another handover will be necessary. Consequently, some specific thresholds and rules have to be defined. These could have the form of simple rules such as "if velocity is greater than z m/sec" or "the MNs distance from the access point is greater the x% of the cells radius and it is moving away from it with velocity at least y m/sec" and so on. Thus, it is clear that this kind of information will help the Core Network make better decisions, avoid unnecessary handovers, and thus reduce the total amount of signalling.

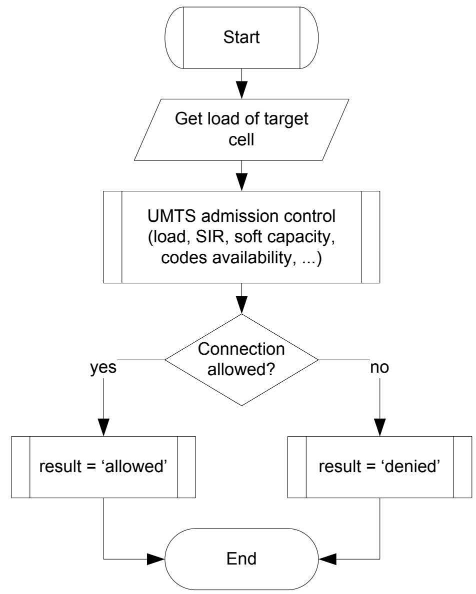


Fig. 5. Handover evaluation procedure in UMTS

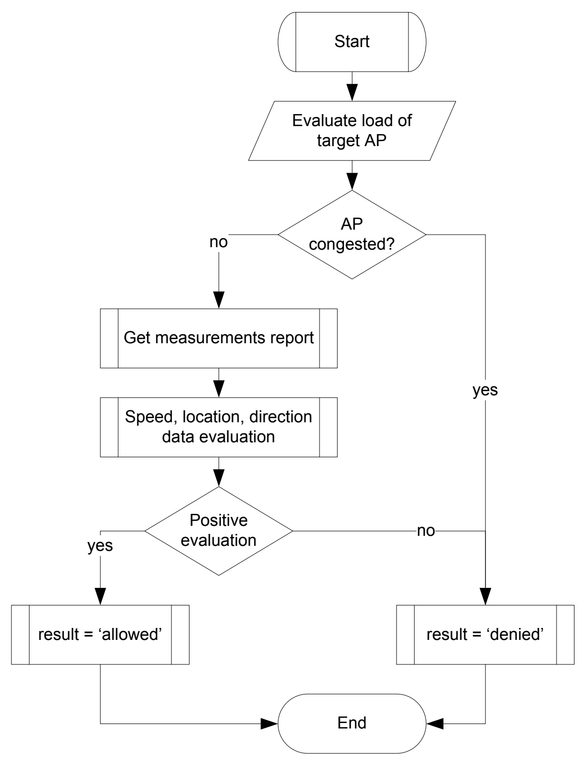


Fig. 6. Handover evaluation procedure in WLAN

The next step in the algorithm is a nested loop. The outer

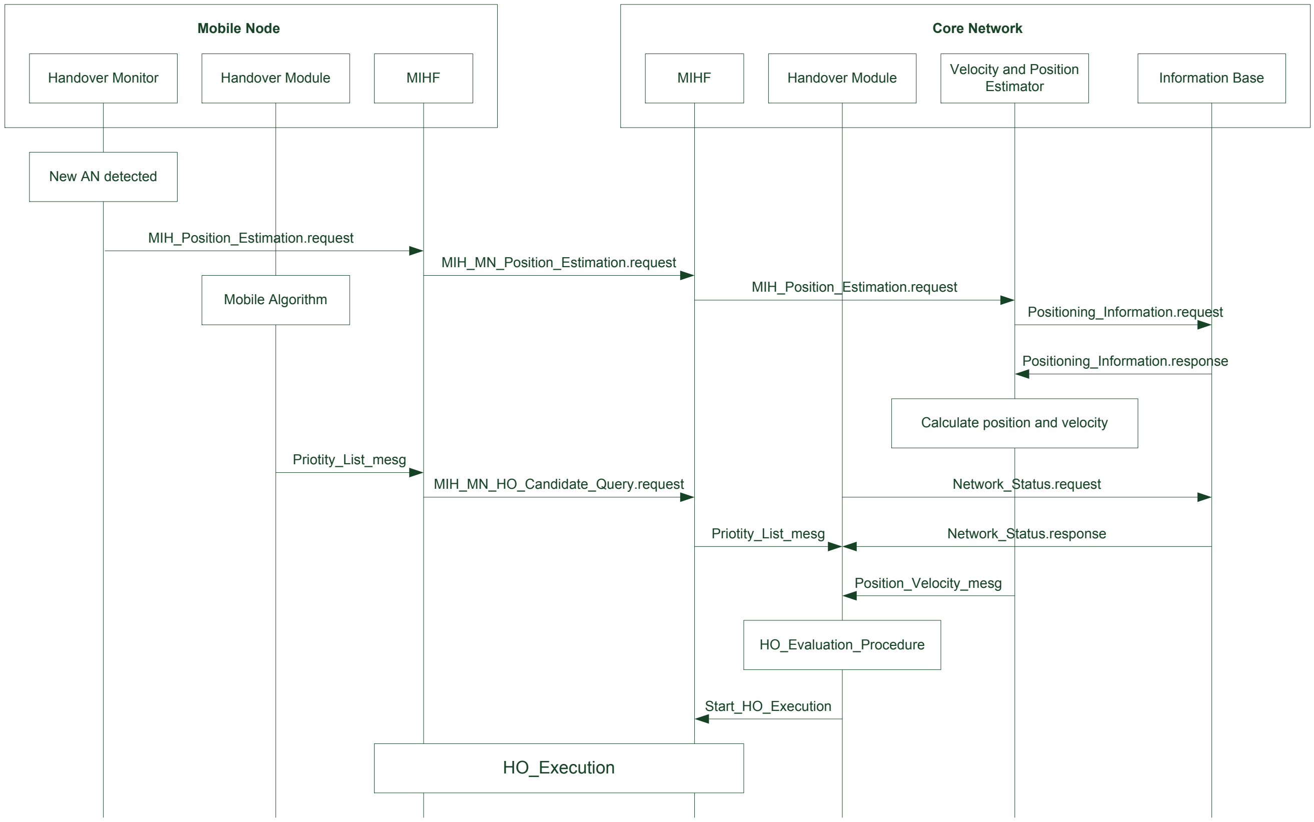


Fig. 7. Handover evaluation procedure in WLAN

loop is executed for each one of the active connections of the MN and the inner loop for each alternative AN for a specific connection $i(i = 1, ..., N)$, where $N$ is the number of active connections and $M$ the number of alternative ANs for each connection. Thus, the algorithm evaluates the handover request for each connection separately. This evaluation is greatly dependent on the AN type. As an example, we consider UMTS and WLAN as alternative technologies. We present some high level descriptions of these two AN evaluation procedures. Figures 5 and 6, present such procedures for UMTS and WLAN respectively.

In Fig. 5, the Core Network has the information of the load of the target cell and the usual UMTS call admission control algorithm is executed. If the result is that the new connection can be supported then this procedure returns the result 'allowed', otherwise the result 'denied'.

In Fig. 6, the high level procedure for evaluating a vertical handover to WLAN is presented. The Core Network has the information on the load of the target access point (AP) and if it is congested, the procedure returns the result 'denied'. Else, since the coverage area of an AP is rather small, the core network has to consider the velocity and the location of the MN to make a decision. Thus, it collects all measurement information and evaluates it. Then, if the result indicates that the new connection can be supported, the procedure returns the result 'allowed', otherwise the result 'denied'.

Finally, a message sequence chart of the signalling during a handover procedure is depicted in Fig. 7. The Handover Module detects that a new AN is reachable with adequate signal quality, and triggers the MIHF in the MN to start the procedure for a potential vertical handover. The MIHF in the MN, notifies the respective entity in the Core Network, to start performing measurements in order to estimate the position and the velocity of the MN. In parallel, the algorithm in the MN is executed. When the execution completes, a message with the priorities of the available ANs for each connection of the MN, is sent to the Core Network. At this point, the measurements for the velocity and the position of the MN stop, and the Handover Module in the Core Network makes the final handover decision. Then, the handover execution procedure is initiated.

## V. Conclusion

In this paper we proposed a mobile-assisted vertical algorithm based on the IEEE 802.21 framework. It introduces two novel characteristics compared to related work. First, is considers each connection separately, as a different handover case. This has the advantage of more appropriate AN selection for each connection based on its specific parameters. Second, the proposed algorithm is split into two distinct and cooperating modules. The first module runs in the MN and creates a prioritized list of the available ANs per active connection, taking into account the user's preferences and the status of the MN. The second module runs in the Core Network and takes the final decision based on the prioritized list received by the MN, the network load conditions, and the MN movement parameters. The separation of the algorithm into two modules decreases the network load and speeds up the handover procedure.

Future work includes a detailed analysis of the modifications needed to be introduced in the IEEE 802.21 framework. In addition, simulations should be conducted to evaluate the performance of the proposed solution.

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