Multihomed Mobile IPv6: OPNET Simulation of Network Selection and Handover Timing in Heterogeneous Networking Environments

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Abstract

Mobile telephone handsets, laptops, and PDAs are today typically equipped with multiple radio access interfaces. The opportunity to connect to more than one access network at a time makes users capable of roaming over access technologies and administrative domains seamlessly. Soft hand-overs can easily be implemented and load balancing is possible to leverage when the amount of traffic exceeds the capacity of one single radio access interface.

Using an IP overlay network and handling mobility management at the network layer is one import candidate for tomorrow's networking architectures. Mobile IPv6 with its extensions for fast hand-overs and hierarchies of mobility anchor points is a concrete implementation of such an architecture. Adding multihoming functionality to Mobile IPv6, basically allowing a mobile node to connect to more than one gateway in different subnets simultaneously, is yet a step towards the efficient implementation of the foreseen architecture.

In this paper, we describe an OPNET implementation of multihomed Mobile IPv6 using one IEEE 802.11 radio access interface (WLAN) and one IEEE 802.16 (WiMAX) interface in the mobile node.

1. Introduction

Future handsets will be equipped with multiple radio access network cards. Technologies including 2G, 2.5G, 3G, WLAN, and WiMAX will be available offering different throughput, delay characteristics, and coverage at various cost levels. 4G is not fully defined yet, but it will most likely consist of an IP overlay network offering its users seamless access to real-time multimedia services like VoIP, IPTV, video conferencing, and networked games.

Important decisions on mobility management schemes and the structure of the IP overlay network still needs to be taken. This article proposes a solution based on Mobile IP and multihoming in combination with a handover decision model using round-trip times (RTT) and RTT jitter forming a metric to compare different access network relative performances. A node model for a multihomed mobile node implementing simultaneous access to WLAN and WiMAX is implemented for OPNET Modeler 12.0.

The rest of the paper is organized as follows: Section 2 surveys different mobility management at various layers. Section 3 introduces Mobile IP, while section 4 outlines the proposed architecture. Section 5 covers information on the developed OPNET Simulation Model. Section 6 presents our results and section 7 concludes the work and outlines future work.

2. Mobility management architectures

Mobility management consists of two fundamental operations: handoff and location management [1]. Handoff introduces a number of questions, notably how to determine the timing of the handoff, the decision on what access network to transfer the traffic to (also referred to as network selection), and how to migrate existing connections smoothly. Location management is the mechanism for locating the mobile node (MN) or a user in order to initiate and establish a connection.

Users of heterogeneous networks with multiple access networks included need a mobility management solution at layers above the data-link layer in order to leverage all available technologies at a certain moment and a certain place. Today there are solutions available at the application layer, the transport layer, and the network layer. Various proposals on cross-layer designed solutions also exist. The IEEE is currently working on a standard for media-independent hand-over services under the name of 802.21 [2].

The most known example of mobility management at the application level is to make use of the emerging Session Initiation Protocol (SIP) [3]. Location management is handled through SIP Registrar servers while connection migration is handled by using re-INVITE messages [4].

Parts of the research community have also paid interest to the transport layer when introducing mobility management [5]. The Stream Control Transmission Protocol (SCTP) [6] is an end-to-end, connection-oriented protocol that supports transport of data in independent sequenced streams. SCTP supports multihoming and combines the datagram orientation of UDP with the sequencing and reliability of TCP. Cellular SCTP (cSCTP) [7] is an extension to SCTP making hand-overs smoother by sending data via multiple paths during hand-overs.

Handling mobility management at the network layer has several advantages since applications do not need to be aware of mobility. If the network layer handles mobility management entirely, applications can, in theory, be used as if the user was running the application in a fixed environment since the user is reachable through a stable (fixed) IP address. The network layer is extended with a suitable mobility management module taking care of the delivery of packets to the user's current point of attachment to the Internet. This mobility management solution works both for connection oriented flows (i.e. TCP connections) and connection less flows (i.e. UDP traffic).

Our proposal is based on a solution with mobility management handled at the network layer using Mobile IP (MIP). Similar proposals have been discussed in the research community recently [8].

3. Mobility management with Mobile IP

The most well-known example of mobility management at the network layer is MIP which is defined both for IPv4 [9] and IPv6 [10]. One of the basic challenges to deal with when introducing mobility management at the network layer is that network layer addresses (i.e. IP addresses) not only are used to identifying hosts but also to finding routes between hosts on the Internet. The IP addresses are said to be semantically overloaded.

MIP makes use of a mobility agent located in the home network, a home agent (HA), and, in MIP for IPv4, a mobility agent in the visited network, a foreign agent (FA). The HA is a specialized router responsible for forwarding packets aimed for the end-user at the MN. The MN is assigned a home address (HoA) in the same subnet as the HA. The FA is responsible for assigning a care of address (CoA) for the MN and forwarding packets for the MN. The HA holds a binding cache with mappings of HoAs to CoAs. The MN can also use a co-located address (cCoA). In that case, the MN acquires an IP address using regular mechanisms like DHCP and is not dependent on the existence of an FA in the visited network.

Packets are transported from the originating host, the correspondent node (CN), to the HA and then tunnelled through an IP tunnel using IP in IP encapsulation to the MN (possibly via the FA). The MN continually sends binding update (BU) messages to the HA indicating its CoA. If a new CoA is indicated in the BU message, the HA updates the binding cache. The HA then returns binding acknowledgment (BAck) messages to the MN. Packets in the direction from the MN to the CN can be sent directly to the CN. In MIPv6 route optimization techniques also exist enabling the CN to send packets directly to the MN if the MN decides to send BU messages to the CN also. Thus, all packets do not need to travel through the HA.

The possibility to register more than one active CoA to the HA and to CNs for a given HoA, often referred to as M-MIP (multi-homed MIP), is described in [11].

4. Reference architecture

The reference architecture in our solution is based on multihomed MIPv6 (M-MIPv6) to support seamless mobility. The MN is typically connected to the HA via various wireless access networks like WLAN, WiMAX, UMTS, and CDMA as well as wired connections. No route optimization is used in the reference architecture making all packets having to pass the HA.

The MIP part of the MN consists of the physical interfaces for each access network along with a virtual interface. BU messages are sent in parallel over all physical interfaces, typically every second using UDP datagrams on port 434. The HA immediately replies on each BU message issuing a BAck message. Round-trip times (RTT) and RTT jitter values are computed based on the BA messages forming an RNL (relative network load) value [12]. The RNL metric represents a quality value for each access network. RTT and RTT jitter values are access technology independent and good indicators on congestion in networks and limitations in bandwidth.

RTT jitter, being the variation in RTT and the mean deviation of the difference in arrival time of two consecutive BAck messages compared to sending time of two consecutive BU messages (being equivalent to the variation in transit time of two BU-BA message pairs), is calculated using formulas in RFC 3550 [13]. The formula is adjusted with a variable history window instead of using a fixed history window of 16 (as in RFC 3550) giving the following formulas:

$$RNL_n = \bar{z}_n + c * J_n \quad (1)$$

$$\bar{z}_n = \frac{1}{h} RTT_n + \frac{h-1}{h} \bar{z}_{n-1} \quad (2)$$

$$RTT_n = R_n - S_n \quad (3)$$

$$D_n = R_n - R_{n-1} - (S_n - S_{n-1}) = (R_n - S_n) - (R_{n-1} - S_{n-1}) =$$

$$= RTT_n - RTT_{n-1} \quad (4)$$

$$J_n = \frac{1}{h} \mid D_n \mid + \frac{h-1}{h} J_{n-1} \quad (5)$$

Where, S_i and R_i are defined as

S_i = the time of sending BA message i

R_i = the time of arrival of BU message i

h determines the history window for the weighted average calculations. For example, when $h = 5$, the most recent value will contribute to the calculated $\bar{z}_n$ and J_n values with 20%. This way, hysteresis could be avoided if the value of h is carefully selected.

c determines the weight of the RTT in comparison to the RTT jitter value. For example, when $c = 5$, the RTT jitter value is contributing five times more to the metric value than the RTT value does.

The variables $\bar{z}$, D, and J are initialized with the following values:

$\bar{z}_0 = RTT_0$

$D_0 = 0$

$J_0 = 0$

Using RTT and RTT jitter values on the round trip MN-HA-MN is beneficial since it is absolutely access network independent and no synchronized clocks are needed. The decision is taken whether to make a handover or not, and in the case of a handover to which access network to switch over to.

The handover is performed by redirecting the tunnel from the current access network to the target access network. A separate flag in the binding update message is used to indicate what interface is currently selected by the MN. Figure 1 shows a scenario of an MN connected to both a WLAN and a WiMAX network.

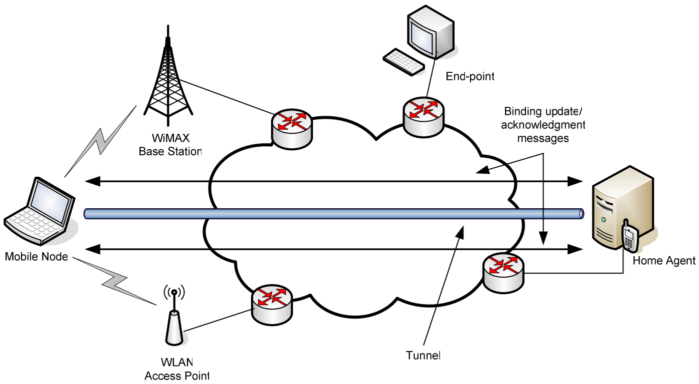

Figure 1: System overview.

The signaling scheme is depicted in Figure 2 where a session is first initiated where there is both WLAN and WiMAX coverage available and WLAN is initially selected (which is indicated by the N-flag being set). The BU messages are sent periodically over both interfaces. After the initiation procedure, BU and BAck messages are sent periodically over both interfaces. This procedure will keep on until a handover decision is made. When the handover decision to WiMAX is taken by the MN, a BU message is sent over the WiMAX access network with the N-flag set in order to inform the HA to redirect incoming traffic to that particular interface. The HA, in turn, replies with a BAck message and indicates that future traffic will be redirected to the WiMAX interface.

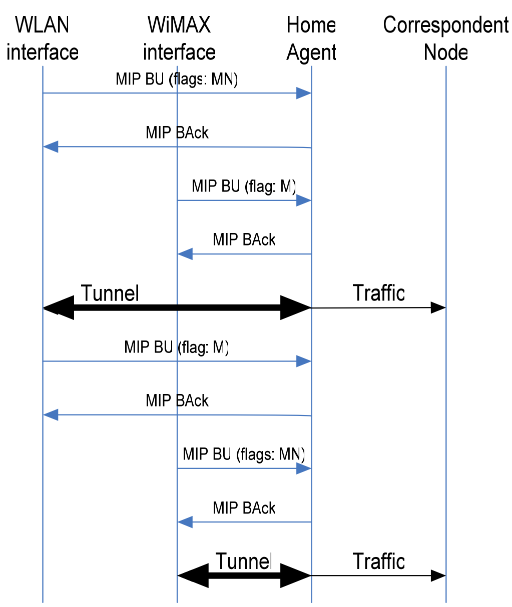

Figure 2: Signaling scheme.

5. The OPNET simulation model

The developed node models are based on OPNET Modeler 12.0 PL5 for Windows XP. In order to simplify simulations and to focus on the relative performance of various access networks types, station types of node models are used. This means that BU/BAck messages and payload traffic is sent directly over the MAC layers in the different access networks.

New node models are developed for the mobile node and for the home agent. The node model for the mobile node (see figure 3) consists of WLAN and WiMAX access, tunneling functionally and MIP registration handling. MIP registration messages are implemented as one source (based on the bursty_source process model) per interface. The node model also consists of an implementation of the decision model described earlier.

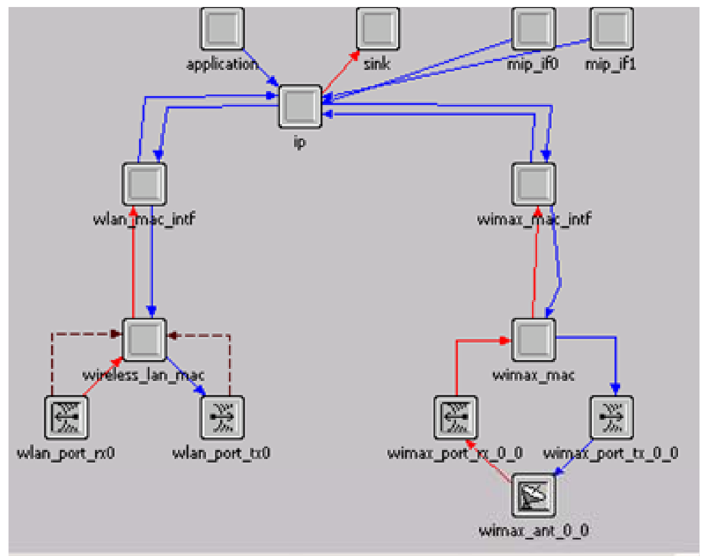

Figure 3: Node model for the mobile node.

The node model for the home agent (see figure 4) is based on the ethernet_station_adv model and contains a MIP process handling registrations, incoming traffic, and outgoing traffic.

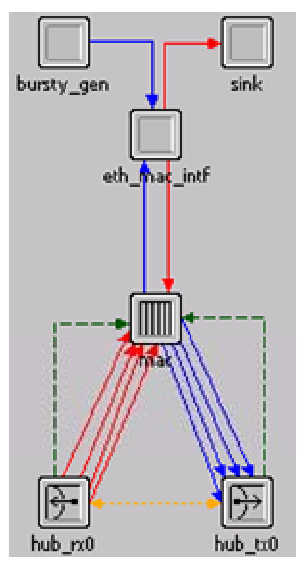

Figure 4: Node model for the home agent.

The WiMAX base station node model (see figure 5) is based on the WiMAX Consortium wimax_bs_ethernet4_slip4_router. The MAC layer is accessed through a wimax_mac_intf process model implemented like the wlan_mac_intf and the ethernet_mac_intf process models. The default service class is used for all traffic over WiMAX.

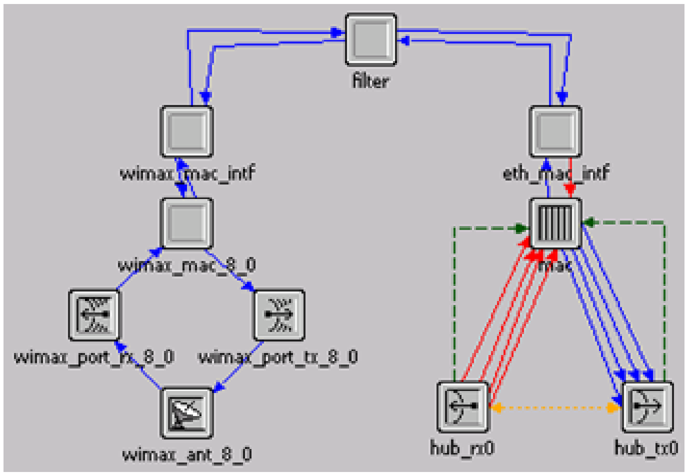

Figure 5: Node model for the WiMAX BS.

Two new packet types are introduced: simple_BU and simple_data used for registration messages and for payload traffic respectively.

The decision model for performing network selection and taking hand-over decisions is implemented using interrupts of type OPC_INTRPT_SELF. This way, the decision model works continually even if one or more of the interfaces are down.

6. Results

In order to evaluate the developed simulation model and architecture as a whole, a two-way 64 kb/s stream was added starting to send 10 seconds after start. The mobile node is following a trajectory at a speed of 10 m/s traveling a distance of 10 km. One WLAN AP is placed 2.5 km at the trajectory after 2,5 km from start covering parts of the simulation area. A WiMAX BS is placed 5 km from start covering the whole evaluation area. The evaluation setup is depicted in figure 6.

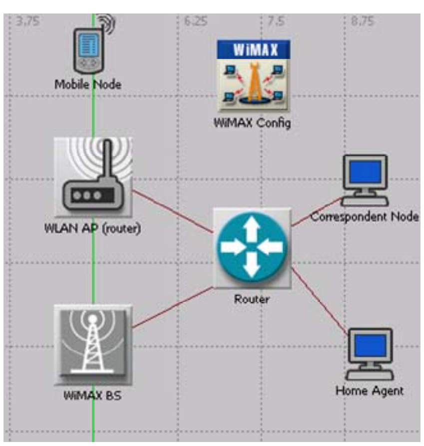

Figure 6: Basic evaluation topology.

The developed model and its embedded decision model for network selection and timing of hand-over decisions works according to the architecture model in section 4.

Results from the basic evaluation scenario are shown in figures 7-11.

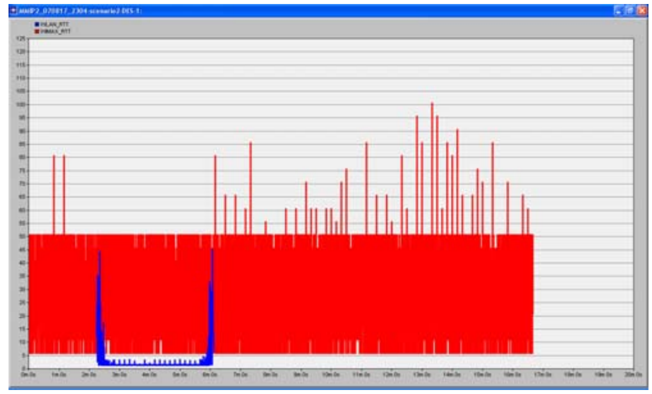

Figure 7: Round-trip delays in MIP BU/Back messages (WLAN/WiMAX).

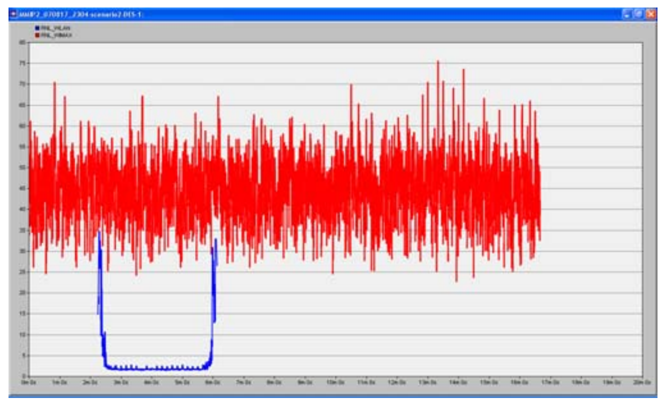

Figure 8: RNL values (WLAN/WiMAX).

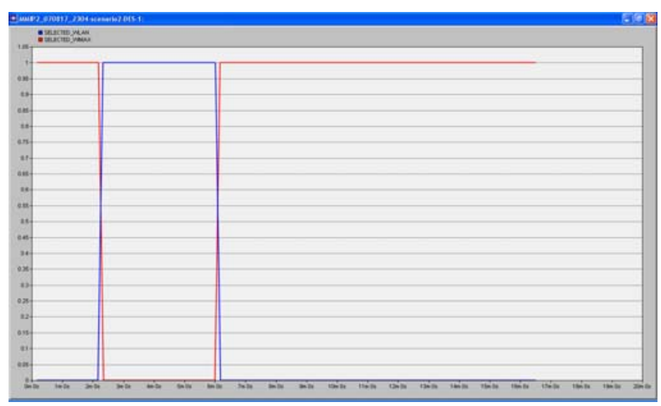

Figure 9: Selected access networks.

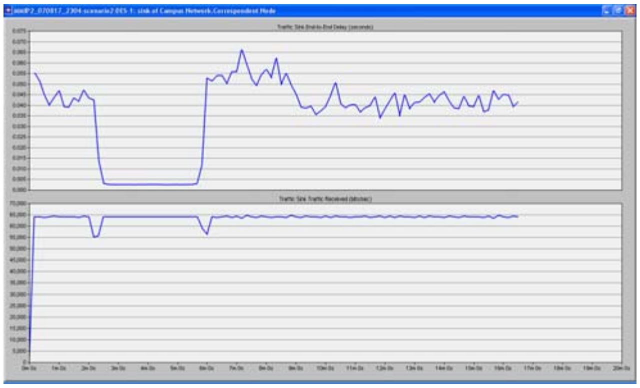

Figure 10. End-to-end delay for payload traffic and received bandwidth at correspondent node.

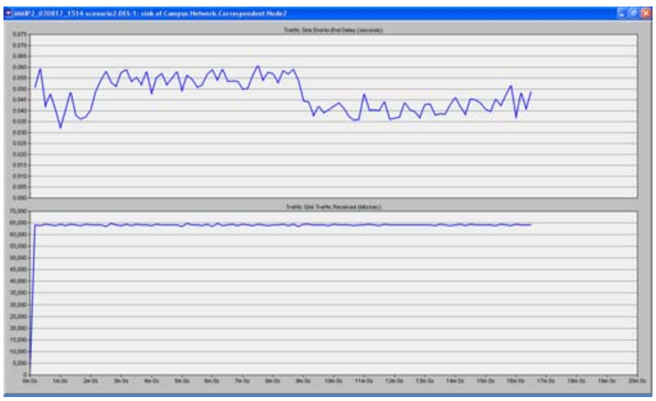

Figure 11: Baseline comparison (only WiMAX).

7. Conclusions and future work

We have shown a simplified implementation of multihoming for Mobile IPv6 in a heterogeneous networking environment. The conclusion is that the multihomed version of Mobile IP (M-MIP) makes soft hand-overs to work. Also, the decision model works for the scenario we tested. Finally, the OPNET Modeler tool is very suitable for simulating these types of experiments and evaluations of new architectures and proposals. We have performed live tests in a real-world environment in parallel [15] with similar results achieved.

We intend to extend the developed node model with support for more radio access networks (UMTS), to implement full-stack support, to implement port-based handling of different flows [14], and to let the decision model be influenced by parameters from other layers than the network layer. Finally, triggers from lower layers will also be used in future versions in order to make the solution even more responsive to varying network conditions.

More sophisticated evaluation scenarios will also be added later on.

Acknowledgments

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References

[1] I.F. Akyildiz, J. McNair, J.S.M. Ho, H. Uzunalioglu and W. Wang, Mobility Management in Next-Generation Wireless Systems, Proceedings of the IEEE, Volume 87, pp. 1347-1384, August 1999

[2] www.ieee802.org/21

[3] J. Rosenberg, H.Schulzrinne, G. Camarillo, A. Johnston, J. Peterson, R. Sparks, M. Handley, and E. Schooler, SIP: Session Initiation Protocol, IETF, RFC 3261, June 2002

[4] H. Schulzrinne, and E. Wedlund, Application-layer mobility using SIP, Mobile Computing and Communications Review archive, Volume 4, Issue 3, pp. 47-57, July 2000

[5] W. M. Eddy, At what layer does mobility belong?, IEEE Communications Magazine, Volume 42, Issue 10, pp. 155-159, October 2004

[6] R. Stewart, Q. Xie, K. Morneault, C. Sharp, H. Schwarzbauer, T. Taylor, I. Rytina, M. Kalla, L. Zhang, and V. Paxson, Stream Control Transmission Protocol, IETF, RFC 2960, October 2000

[7] I. Aydin, W. Seok, and C. Shen, Cellular SCTP: A Transport-Layer Approach to Internet Mobility, In Proceedings of the 12th International Conference on Computer Communications and Networks, pp. 285-290, October 2003

[8] Q.-T. Nguyen-Vuong, N. Agoulmine, and Y. Ghamri-Doudane, Terminal-Controlled Mobility Management in Heterogeneous Wireless Networks, In IEEE Communications Magazine, Volume 45, Issue 4, pp. 122-129, April 2007

[9] C. Perkins (ed.), IP Mobility Support for IPv4, IETF, RFC 3344, August 2002

[10] D. Johnson, C. Perkins, and J. Arkko, IP Mobility Support in IPv6, IETF, RFC 3775, June 2004

[11] C. Åhlund, R. Brännström, A. Zaslavsky, M-MIP: Extended Mobile IP to Maintain Multiple Connections to Overlapping Wireless Access Networks, In Lecture Notes in Computer Science, Volume 3420/2005, pp. 204-213, April 2005

[12] C. Åhlund, R. Brännström, A. Zaslavsky, Traffic load Metrics for Multihomed Mobile IP and Global Connectivity, In Telecommunication Systems, Volume 33, Number 1-3, pp. 155-185, October 2006

[13] H. Schulzrinne, S. Casner, R. Frederick, and V. Jacobson, RTP: A Transport Protocol for Real-Time Applications, IETF, RFC 3550, July 2003

[14] R. Brännström, C. Åhlund, K. Andersson, and D. Granlund, Multimedia Flow Mobility in Heterogeneous Networks using Multihomed Mobile IP, In Journal of Mobile Multimedia, Volume 3, Number 3, pp. 218-234, September 2007

[15] www.hybrinet.org