Interworking Wireless MAN and LAN systems – from Theory to Demonstration

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***Abstract*—Next generation networks aims at proposing a spectrally efficient broadband access by using fixed wireless routers to provide high capacity and high radio coverage. These fixed wireless routers might be based on heterogeneous interworking standards, e.g. by a dual standard delivery of HiperMAN and HiperLAN/2. This paper studies several interworking/bridging mechanisms between HiperMAN and HiperLAN/2. Simulations have been carried out to further evaluate the most promising solution. Moreover, its feasibility is shown by demonstration.**

I. Introduction

Wireless Metropolitan Area Networks (WMAN) will hence be a relevant candidate for new access infrastructures. One of the main shortcomings is that they do not provide indoor coverage. An efficient solution for the interworking of WMANs and wireless LANs (WLAN) to provide indoor coverage would largely contribute to the commercial success. In this paper several interworking mechanisms for the standards HiperMAN (HM) and HiperLAN/2 (H2) have been investigated and compared. It turned out that the bridging on Ethernet level represents the best trade-off between Quality of Service (QoS) guarantees and implementation complexity.

In section II three interworking methodologies are presented. Section III shows the performance of the Ethernet-bridging solution through simulations. In section IV a congestion control mechanism is presented that enables the interworking system to handle temporary congestion / interference situations. The performance of this congestion control mechanism is shown by simulations. Finally, section V presents the demonstrator that has been developed and a comparison between the simulation results and the demonstrated results is provided. Conclusions are drawn in Section VI.

II. Interworking Methodologies

The interworking between WMAN and WLAN can be implemented at different protocol levels such as IP, Ethernet or DLC/MAC level (refer to Figure 1).

A. Bridging at IP Layer

Both systems do have an IP convergence layer and IP version 6 (IPv6) provides functionality to support QoS. Since there is no control plane in the IP layer to transport information of lower layers from one system to another, only the user plane could be used to exchange QoS parameters between H2 and HM. IPv6 provides two header fields to support QoS, the "Traffic Class" and the "Flow Label".

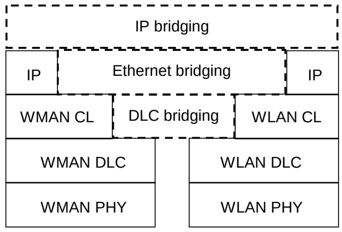

Figure 1: Overview of possible interworking levels

The 8-bit **Traffic Class** field is available for use by originating nodes and/or forwarding routers to identify and distinguish between different classes or priorities of IPv6 packets [1]. It indicates how each node in the network should handle the packet (per hop behavior). The first three bits determine the relative priority of that packet, thus 8 different classes have been defined. The last three bits allow a differentiation within precedence levels.

IPv6 **Flow Label** is defined as a 20-bit field which may be used by the source to label sequences of packets for which it requests special handling by the IPv6 routers, such as non-default QoS or "real-time" service [1]. The Flow Label is a pseudo-random number that is unique when combined with the source address. The all zero Flow Label is reserved to indicate that no Flow Label is being used. It is required that all datagrams with the same (non-zero) Flow Label must have the same destination address, hop-by-hop options header, routing header and source address contents. The notion is that by simply looking up the Flow Label in a table, the router can decide how to route and forward the datagram without examining the rest of the header.

1) Interworking mechanism based on Traffic Class

In H2 8 different priorities can be assigned to a connection. Since IPv6 provides the Traffic Class field to indicate priorities, the H2 convergence layer has to map the priority indicated by the Traffic Class field to the corresponding H2 priority. HM on the other hand uses Service Flows (SF) containing specific QoS parameters. In order to use the Traffic

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Class field for QoS negotiation, SFs need to be pre-provisioned and associated with different priority levels. As this solution limits the H2-HM system to 8 different QoS levels, other mechanisms based on the Flow Label have been explored.

2) Interworking mechanism based on Flow Label

The Flow Label field was intended to be a pseudo random number but we propose to give a special QoS-format to these 20 bits. Within this new definition the Flow Label would be divided into six subfields:

- **Index** (1 bit) indicates the Flow Label approach to be used. A value of 1 indicates a random number and 0 specifies the QoS-format.
- **Reserved** for future use are the following 3 bits.
- **Counter** (4 bits) differentiate between two different connections of one source with exactly the same QoS parameters but with different destination addresses.
- **Delay** requirements are specified with 4 bits.
- **Jitter** (4 bits) gives the maximum tolerable value.
- **Bandwidth** (4 bits) specifies the required bandwidth.

A HM SF could be created based on the Flow Label QoS parameters and the Traffic Class. A connection Identifier (CID) is assigned to the SF and a classifier is set up including the criteria Flow Label. During an active connection all IP packets matching the classifier are mapped onto the assigned CID. Temporary dynamic changes of QoS settings for a certain connection could not be done with this approach.

By means of the QoS-format of the IPv6 Flow Label and the Traffic Class, specific QoS requirements could be announced to all systems serving the IP packet from source to destination in general. The system independent QoS requirements of the IP datagrams could be mapped onto system dependent QoS contexts like HM Service Flow or H2 priority. It is also possible that other wireless systems like GSM/GPRS or UMTS interpret these values and map them to their own QoS contexts.

B. Ethernet Bridiging

This solution uses the *Convergence Sublayers* (CSs), such that the interworking mechanism is made independent from the lower layers. Moreover, the introduction of the Ethernet *Service Specific Convergence Sublayer* (SSCS) [2] in H2 allows the use of the Ethernet QoS support by inserting a 3 bits user priority in the Ethernet frame or by using the user priority field included in the TAG header of the 802.1ac frame. This TAG header identifies one of the eight priority levels, as defined in the IEEE 802.1p extension of the standard IEEE 802.1D [3].

In Figure 2 all actions to transfer data in the uplink direction (MT/Bridge/BS) are shown. The Ethernet packets come from the higher layer containing the user priority in the TAG header field. The functions implemented by the Ethernet SSCS user plane include the traffic class mapping according to 802.1p. This function provides the mapping of different traffic classes to different priority queues, depending on how many priority queues are supported. IEEE 802.1p defines 8 priorities and describes which type of traffic is expected to be carried in this priority. The mapping between different traffic classes and corresponding *DLC Connection* (DLCC) IDs is described in [4]. After connection set-up the RLC indicates which DLCC IDs have been assigned to DLCCs in a list and traffic classes are mapped to DLCC IDs depending on the numerical order of the value of the DLCC IDs. When packets arrive at the H2 side of the bridge, the Ethernet SSCS forwards packets to the HM side of the bridge, in which the classification between every incoming packet and a specific CID, which implicitly identifies a specific SF, is carried out [5]. This classification procedure shall use the user priority value contained in the TAG information field of the frame. So far a traffic classification based on 8 priority values is introduced. Therefore pre-provisioned SFs should be defined so that QoS needs for each type of traffic is efficiently supported.

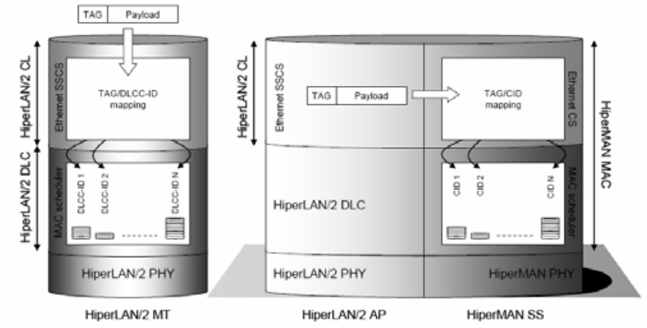

Figure 2: Ethernet interworking mechanism

The advantages of the Ethernet-Bridging are:

- *High applicability to standards.* Even if the focus is on H2 and HM, it is easily applicable to other WLAN systems, e.g., IEEE 802.11e.
- *Low complexity of the implementation.* Implementation of priority tagging in Ethernet CS.
- *Slight complexity of the changes in the involved standards.* Pre-provision of 8 service classes.
- *Flexibility towards evolution of the standards.* Changing the QoS parameters does not change the implementation. It concerns the updating operation of the QoS parameters of the same pre-provisioned SFs at the BS. In this way, the SFs are always referred with the same *Service Class Name* - this updating process is transparent to users.
- *Possible extendibility to multiport.* Use of IEEE 802.1D bridge (including IEEE 802.1p) allows the communication also with other Ethernet-based devices.

The use of the IP Traffic Class has the same capability of handling QoS. The difference is the lack of applicability to 802.11 and the less straightforward integration in the local network (Cellular IP is needed). With respect to the IP approach with Traffic Class and Flow Label, the Ethernet bridging allows a lower granularity of QoS, i.e. the number of different QoS levels that can be specified. However, this approach needs more changes to the standard and the QoS information cannot easily be shared with the network. Moreover, the granularity offered by the Ethernet approach can be considered satisfactory for most of the applications.

C. *Bridging at Data Link Control Layer*

Interconnecting H2 and HM directly at Data Link Control (DLC) level would be fast since the encoding and decoding of the convergence layers could be bypassed and the transmission via network layer protocols like Ethernet or IP could be neglected. Secondly all necessary information concerning the link quality, queue fill levels etc. could be exchanged since they are visible in the DLC layer. Regarding the control messages, both DLC layers could be connected. The functionality of the layer 2 bridge would be to transform the H2 DLC service primitives into the corresponding HM MAC service primitives. But PDUs containing data can not be directly transmitted from one DLC layer to the other, because the CS of the systems does not have the same functionality, e.g. segmentation / reassembly or optional header suppression. That disables the interworking on DLC level.

III. INTERWORKING SIMULATIONS

This section shows the performance of the interworking mechanism of HM and H2 by means of throughput and delay measures. The first set of results has been obtained with an SDL-based simulation environment that is composed of an HM as well as an H2 protocol stack. As the Ethernet approach appeared to offer the best trade-off between performance and complexity, the following simulations use the Ethernet TAG field as explained in section II.B. Both systems perform priority queuing based on that 3-bit field. The basic scenario is composed of 1 H2 mobile terminal (MT) associated to a H2 access point (AP) that is interworking with a HM subscriber station (SS). Figure 3 illustrates how the scenario is configured. Only one connection has been set in each direction, uplink (UL) and downlink (DL). A detailed system set-up can be found in [6].

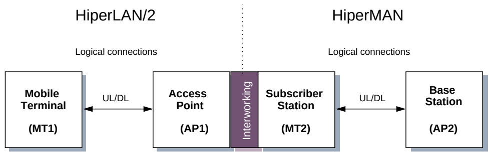

Figure 3: Basic scenario

A mean rate of 3.6 Mbps for the DL and UL connection has been set. Two times 3.6 Mbps are 60 % of the nominal net PHY rate of QPSK 1/2, which is 12 Mbps. With the prefixed modulation and coding scheme both systems are able to handle the load.

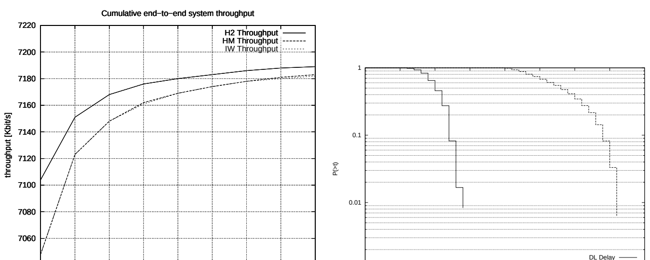

Figure 4: End-to-end throughput [kbps] and delay [ms]

In Figure 4 the system throughput can be observed, i.e. DL and UL data is cumulated and divided by the simulation time. The level of saturation lies at 7.2 Mbps, the data rate of the traffic source. Due to a shorter frame length and therewith a shorter synchronization phase, the H2 system starts its transmission earlier and thus, H2 throughput is slightly higher. Note that the graph is focused on the region of interest. The end-to-end interworking throughput is of course the throughput of the system with the lower throughput rates, which is the HM system in this scenario. Figure 4 also shows the complementary cumulative distribution function (CDF) of the packet delay. The minimum delay for DL starts around 6 ms, which is approx. the addition of the HM DL subframe and the DL phase of the H2 MAC frame. The minimum UL value starts around 20 ms due to the bandwidth request mechanism. The best effort uplink scheduling service allows requesting bandwidth only by contention request. Thus the delay of the bandwidth request in the UL direction enlarges the overall delay. Further on it can be seen that 90 % of the packets in the DL face a delay smaller than 12 ms and 90 % of the UL packets face a delay smaller than 34 ms. Mean delay values are summarized in Table 1.

	Mean delay values	
Data rate	downlink	Uplink
7200 kbps	10.24 ms	28.18 ms

Table 1: Mean delay values

IV. CONGESTION CONTROL

The Ethernet bridging allows the negotiation of QoS requirements during the creation of a new interworking connection in a static manner, without any dynamic adaptation of the QoS parameters necessary to optimize the management of some congestion/interference conditions. In [6] it has been shown that whenever an interworking HM-H2 system is running into congestion, capacity is wasted. If the link capacity in one system is temporarily degraded due to a high traffic load in the system or due to interference, two effects could occur:

1. Loss of data due to buffer overflow and therewith unnecessary retransmissions
2. Waste of bandwidth due to unused reservations

The capacity of the corresponding interworking connection should be aligned with the capacity of the bottleneck link. There is no method defined in neither standard which temporarily adapts the Quality of Service (QoS) parameters dynamically during the connection runtime. In HM the existing MAC mechanism is based on a 3-way message exchange. There is no difference between the creation of a connection and the change of the parameters, thus all parameters involved have to be signaled and negotiated [5]. The same applies for the H2 standard. The existing DLC mechanism is also based on a 3-way exchange. The modification resets data buffers and ARQ respectively flow control states of the access point and the mobile terminal. It is again like setting up a new connection [4]. [7] proposes a new congestion control mechanism to dynamically adapt the QoS demands of a certain connection during runtime. Due to the temporary nature of congestion/interference situations, the proposed congestion control mechanism is working on a temporary basis, i.e. an automatic recovery is included. The congestion control mechanism is working in the DLC/MAC layer.

Figure 5 shows the effectiveness of the congestion control mechanism of the HM-H2 bridge for a congestion in the H2 downlink. When a connection on the H2 link gets congested, this information is returned to the HM BS and causes a change in scheduling. The configuration of the network is shown in Figure 6. The effective data rate of the HM is 12.80 Mbps and the effective data rate for the H2 is 10 Mbps. In absence of congestion in the H2 link, the video stream uses most of the link capacity and reaches its maximum data rate (9 Mbps), whereas the low priority data flow gets the rest of the available bandwidth (1 Mbps). When a congestion event occurs in the H2 side, for instance when the MT with which the AP communicates moved out of range, the connection linked to the high priority video streaming is stopped and the congestion control mechanism passes this information to the HM terminal. This terminal stops the video streaming as well and, consequently, the low priority data flow consumes the whole bandwidth in the H2. The fact that the low priority data flow rate rises to 10 Mbps proves that the congestion control mechanism has triggered the HM to switch off the video streaming. Figure 5 has been achieved by simulations made with the WipSIM simulator [8].

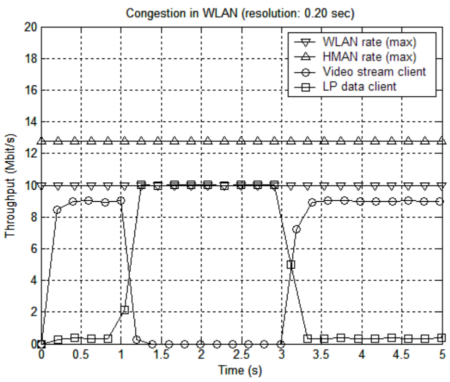

Figure 5: End-to-end throughput for a congestion on the WLAN side

V. Interworking Demonstration

The demonstration system allows evaluating several interworking mechanisms in real life conditions. Here we show the exchange of QOS parameters between the WMAN and WLAN parts, for scenarios with and without congestion.

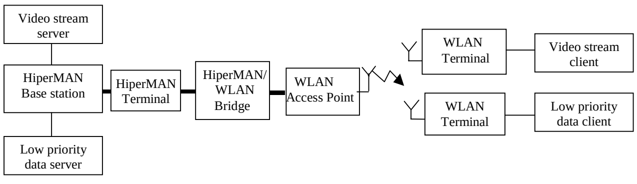

Figure 6: Interworking demonstrator system overview

The WMAN part of the demonstrator consists of a HM base station (BS) and one SS, while the WLAN part consists out of a H2 AP with two MTs (Figure 6). Here, we briefly summarize the characteristics the main components:

- The HM DLC/MAC layer is mapped on standard PC's parts running the ECOS real time operating system. The physical layer of the HM platform is replaced by a wired Ethernet link (Figure 7).
- H2 functionality is implemented in a Compact PCI rack running the Linux OS. The physical layer functions are implemented on FPGA boards that also host a dedicated soft processor core. The latter runs the low level control functionality of the MAC layer.
- The bridging functionality is prototyped on the H2 AP. In the WLAN system we support priority based scheduling in the bridge (on top of the CS), or below the bridge (in the H2 MAC, below the convergence layer). The first option allows evaluating the QOS techniques on systems without intrinsic QOS support, eg standard wired Ethernet or IEEE 802.11a/g wireless systems.

The functionality of the demonstrator is illustrated with two scenarios, using following traffic sources and sinks:

- A constant bit rate MPEG video sequence is served on a web server, using the HTTP protocol. The resulting traffic is treated as high priority video data. As data sink we use a media player. The bitrate of the selected stream is 2 Mbps.
- A TCP traffic generator is used as low priority data source. The TCP flow control mechanism adjusts the data rate as the capacity of the low priority data link increases or decreases.

In both scenarios, the main traffic flow is from the HM BS side towards the H2 MTs. The HM BS classifies the traffic based on the IP port number, and adjusts the Ethernet TAG to represent high or low priority traffic. Several other options of classification and tagging are supported, both in the HM or H2 parts. These are well known [6], and not relevant for the further treatment. The scheduling policy of the main parts is configured as follows:

- HM: two priority classes, each with a pre-allocated bandwidth and no bandwidth sharing. This can easily be implemented with a pure TDMA scheme.
- H2: round robin packet scheduler.
- Ethernet bridge: priority based scheduling, with bandwidth sharing.

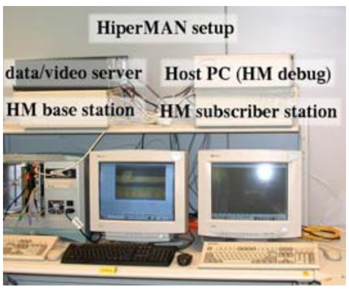

Figure 7: HiperMAN system components

A. *Interworking on Ethernet level scenario*

This scenario shows how the selected configuration reacts when the total capacity in the WLAN system is suddenly reduced. The expected outcome is that the low priority data stream slows down, while the high priority video stream is unaffected. This also indicates that the QOS tags propagate correctly from the WMAN to the WLAN part.

Figure 8 shows the results captured on the demonstrator. The high priority and low priority traffic is generated on a common server, residing on the side of the HM BS side. The throughput plots are captured on this server, and each tick represents one Megabit/s of traffic. The WLAN rate is reduced twice and in each case the low priority data rate drops. The effect of pausing the video stream is also shown, once while the WLAN rate is reduced, and once when the entire capacity is available. This action clearly illustrates the scheduling behaviour of the WMAN (no bandwidth sharing) and WLAN (bandwidth sharing) parts.

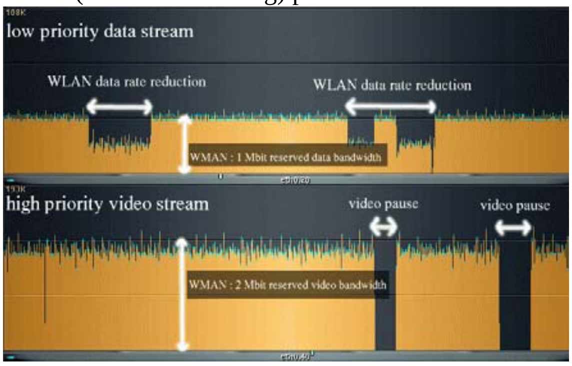

Figure 8: Demonstrator throughput trace

When the bandwidth in the WLAN side is reduced, the throughput of the low priority data stream is reduced first. Several approaches are possible if the high priority connection is idle. Here the WLAN part frees unused capacity for the low priority data stream, while the WMAN part sticks to the reserved bandwidth.

B. *Congestion control scenario*

As an extension of the previous configuration, we evaluated the response of the system to congestion on the high priority video link in the WLAN part. When no specific interworking measures are introduced, the TCP flow control will react upon the congestion and adjust the rate of the video stream. In case the video connection is abruptly blocked, the system response is similar as for a video pause (Figure 8).

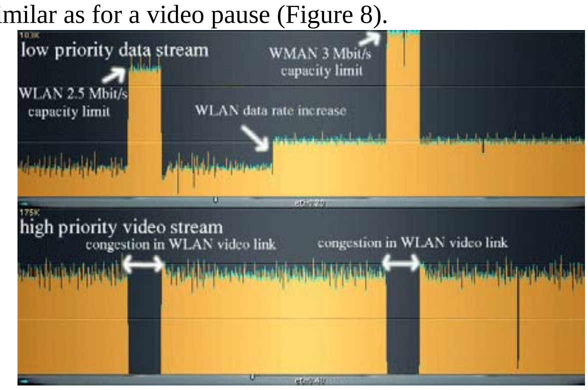

Figure 9: Demonstrator throughput trace

When congestion is detected in the WLAN side, the allocated bandwidth is temporary freed in the WMAN part. Here the high priority video stream experiences congestion, and the corresponding bandwidth is made available to the low priority data stream. This is shown for the case where either the WMAN part or the WLAN part is the bottleneck for throughput.

In contrast, when we use the congestion control interworking mechanism of section IV, the unused reservations of the WMAN part is freed (Figure 9). This was also shown by the simulation results in Figure 5. It should be mentioned that if bandwidth sharing would be implemented in the WMAN part the throughput result of TCP flow control and the congestion control mechanism would be similar. More detailed observations show that the congestion control mechanism is able to react faster on network congestion. Also the mechanism functions for services where flow control is not available.

Still the jury is still out on which mechanism is preferable in what circumstances, and the interworking demonstrator will be used to further investigate these issues.

VI. Conclusion

Interworking mechanisms between WMAN and WLAN, in particular HiperMAN and HiperLAN/2 have been investigated. The performance of the selected mechanism has been evaluated by means of simulation. Finally the feasibility and the effectiveness of the interworking in conjunction with the proposed congestion control mechanism have been demonstrated. Thus, interworking wireless MAN and LAN systems are indeed a promising candidate for future wireless systems.

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