Improving QoS in a Multi-Hop Wireless Environment

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Abstract: This paper focuses on the provision of QoS in a Multi-hop Wireless Network (MHWN) environment. The approach proposed here is based on the introduction of the Wireless Adaptation Layer (WAL), an intermediate layer between the IP layer and the DLC/PHY layers at each communication node within the MHWN. The scope of the WAL is to cope with the wireless channel impairments and provide improved QoS support to the lower layers while, at the same time, be independent and transparent to both higher and lower layers. In this way, the WAL provides a uniform QoS mechanism over a diverse environment such a MWHN.

1. Introduction

Nowadays, the provision of services to the user by means of wireless technologies is becoming more and more extended, with location dependent services occupying a prominent position among the preferences of mobile users. In this respect, Wireless Local and Personal Area Networks (WLANs and WPANs) are evolving as an attractive complement of cellular systems. The short and medium ranges (10m~200m) of pico and micro cells provide several advantages in terms of bandwidth/power utilization, as well as location-based services.

However, connecting a large number of Access Points (APs) by means of wired networks is usually difficult, expensive and impractical, while wireless technologies can be used for that purpose. Towards this direction, solutions for interconnecting APs, of usually different technologies, through wireless medium, have been proposed, leading to Multi-hop wireless networks (MHWN) [1]. Due to their dynamic nature (concerning mainly the incorporated technologies and topology changes due to mobility), MHWNs are subject to constant modification. For example, a mobile terminal (MT) equipped with a WLAN interface has access to the Internet or a corporate Intranet through an access point (AP). The same MT may be a member of a short range wireless Personal Area Network (WPAN) acting as an AP to that network. This WPAN may in turn be interconnected to other WPANs. Another example includes access points (APs) that are connected to an Internet Service Provider (ISP) using long range Fixed Wireless Access (FWA) systems, thereby allowing local exchange carriers to compete with telecom operators and rapidly deploy an alternative (competitive) communications infrastructure. Alternatively, existing or future cellular system infrastructure can be used for the same purpose. A possible arrangement of an MHWN is depicted in Figure 1.

In this example, mobile clients (C) want to access remote servers (S) for example on the Internet. They may connect to APs, either directly using WLAN technology, or by means of relays (R) that support WLANs and WPANs or FWA systems.

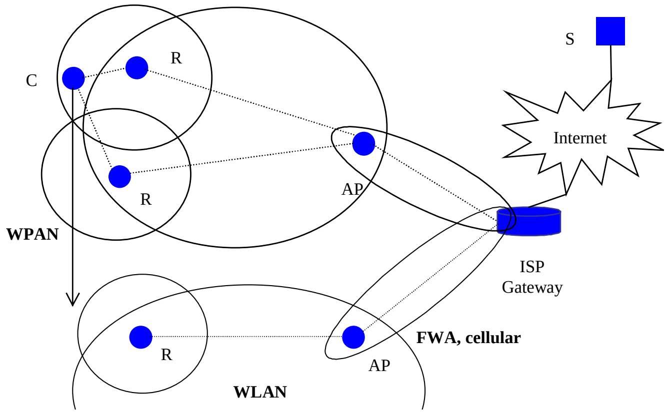


Figure 1 A possible arrangement of an MHWN.

The MHWN approach becomes even more attractive by the fact that mobile terminals are expected to have WPAN capabilities in the near future (e.g., using the Bluetooth standard [2]). This makes interconnection of many different devices possible in small cells. At the same time, terminals are evolving to support multi-mode multi-standard mobility so that it will be possible for the same device to switch the transceiver for example from Bluetooth to IEEE802.11, in order to attach to a WLAN access point (vertical handover). In this way, several WPANs may connect together, e.g., in a conference room, possibly with the help of an ad-hoc infrastructure.

The great diversity and flexibility of MHWNs, together with the different characteristics of the standards involved and the range of possible usage scenarios, impose several new requirements and problems that should be taken into account in a heterogeneous MHWN environment. In particular, the following requirements should be met by a MHWN:

- Routing (reliable, low-complexity and interoperable),
- Security,
- Mobility (including macro- and micro-mobility with vertical handovers),
- Low energy consumption,
- QoS and compensation for link quality variations and interference.

This paper focuses mainly on the last requirement, proposing a general and transparent solution. The proposed solution is based on the introduction of the Wireless Adaptation Layer (WAL), an intermediate layer between the upper network layers (TCP/IP) and the lower wireless layers (DLC/MAC, PHY). Its aim is to cope with the wireless channel impairments and provide QoS to different kinds of traffic. In a later version, the WAL can be extended to provide support for routing optimisation, security and mobility. The paper is organised as follows: Section 2 provides a description of the Wireless Adaptation Layer (WAL) architecture, focusing on the classification of incoming traffic. Section 3 discusses the use of the WAL in a MHWN environment, especially concerning the interworking of different WAL instances operating in a multi-mode node. Finally section 4 contains our conclusions and future plans.

2. Wireless Adaptation Layer (WAL)

The WAL can be implemented in any wireless interface and, as its name implies, it adapts its behaviour according to the higher layers' QoS requirements and observed channel conditions [4]. It provides a uniform interface to IP, while being independent of the underlying wireless network technologies. From a functional point of view, the WAL could be considered as a Performance Enhancing Proxy (PEP) that is used to improve the performance of Internet Protocols on network paths where native performance suffers due to characteristics of a link or subnetwork path [5]. In our case, the WAL intends to improve the performance of Internet protocols operating over wireless links.

The main role of the WAL is to provide improved QoS support. The WAL architecture provides sufficient flexibility and therefore can be configured appropriately so as to reflect the needs of the user services. The main aim is to provide a QoS mechanism that is independent of the underlying WLAN technology, and can be adapted to any kind of IP traffic.

An inside picture of the WAL is depicted in **Figure 2**. It aims to offer performance enhancements by the use of functional modules (X/Y/Z modules), each of which performs a specific operation.

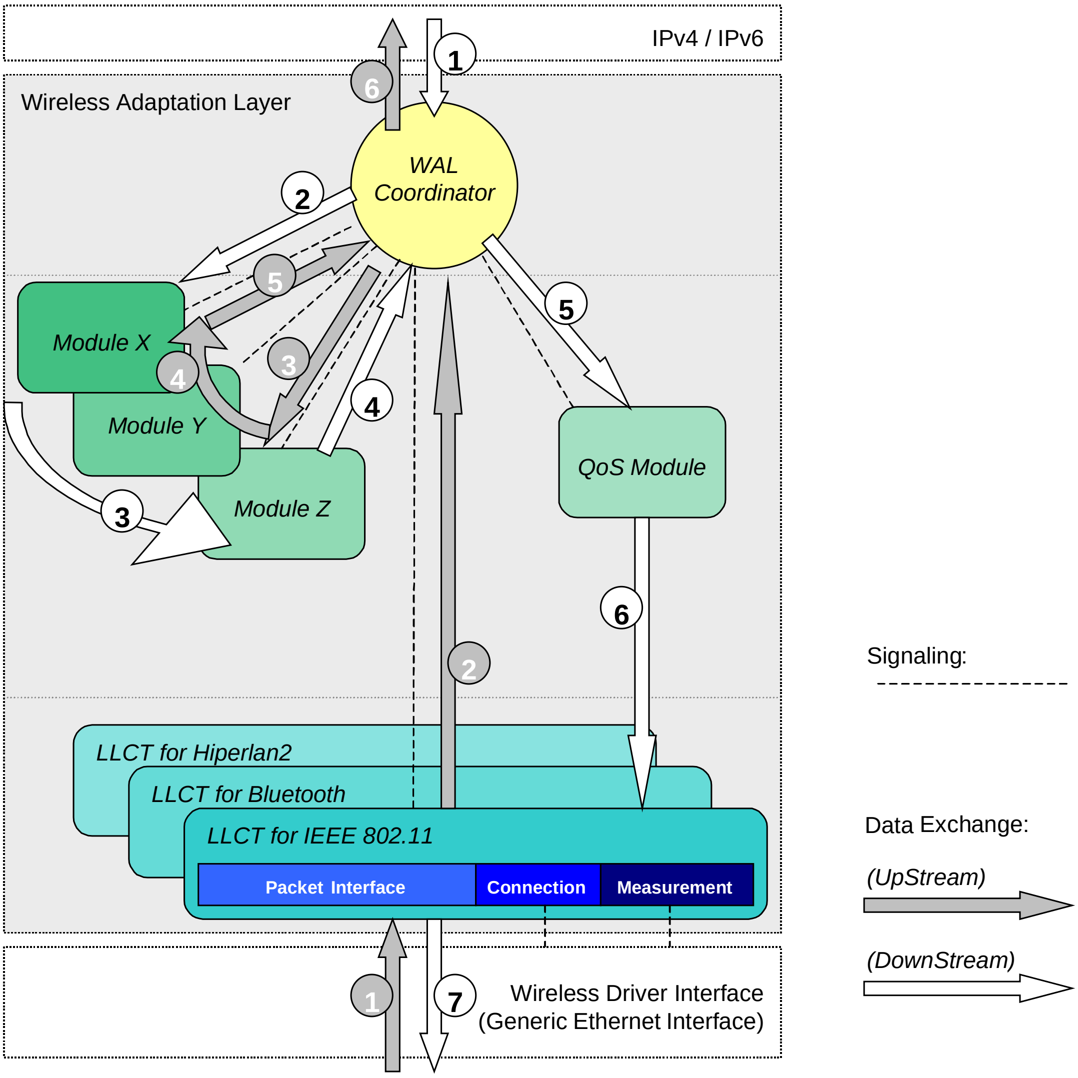


Figure 2. WAL architecture

QoS provision in WAL is based on the concepts of *WAL chains* and *WAL Associations*. A *WAL chain* defines the service offered to a particular set of IP packets and corresponds to a particular sequence of WAL modules that provide such a service. Classification of IP packets into a specific WAL chain is based on several parameters, such as the type of application traffic (e.g., audio/video streaming, bulk transfer, interactive transfer, Web) or the protocol type (e.g. TCP, UDP) etc. , as explained later in this section.

A *WAL association* identifies a stream of IP packets classified for the same WAL chain and destined to or originated from a specific mobile terminal (MT), i.e., *WAL_Association* = *<WAL_Chain, MT_Id>*. In other words, a WAL association corresponds to a particular type of service offered to a particular MT. In this way, we can differentiate the operation of WAL on a per-class as well as a per-user basis. In addition, services for particular users can be customized to meet their specific QoS requirements and to implement a differentiated-charging policy.

Every WAL association can be treated in a different way, based on the anticipated QoS level. Treatment is characterised by the sequence of WAL modules that the packets of a WAL association will pass through (i.e., the WAL chain), as well as the specific parameters of these modules. These parameters can be adjusted dynamically by the WAL Coordinator, based on time-varying channel or traffic conditions.

The **WAL Coordinator** shown in **Figure 2** can be viewed as the central "intelligence" of the WAL. Both downstream (from IP layer) and upstream (to IP layer) traffic passes through the WAL Coordinator before being processed by other modules. In the downstream direction, the WAL Coordinator intercepts IP packets, decides on the WAL chain that these packets should pass through, and appends the WAL header, containing the information required for the operation of the modules. In the upstream flow, the WAL Coordinator accepts WAL frames (encapsulated IP packets, as shown in Figure 3) and passes them through the sequence of modules, associated with the WAL chain, in the reverse order. A detailed description of the structure of the WAL header can be found in [4].

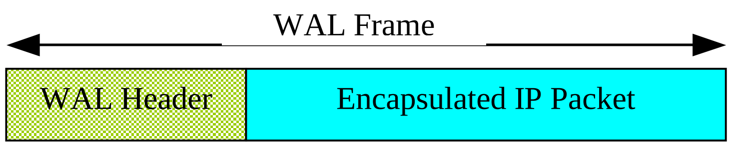


Figure 3. The structure of WAL Frame

The **QoS module** (shown also in **Figure 2**) provides flow isolation and fairness guarantees through traffic shaping and scheduling.

On the other hand, modules X/Y/Z comprise a pool of functional modules, aiming to improve performance in a number of ways. The set of available modules can be extended in future versions of the WAL but so far we have identified the following:

- **ARQ module (ARQ)**: Can be used to improve packet error rate of non-real-time traffic (for example interactive or best-effort).

- **FEC module (FEC)**: Its use is recommended for real-time-traffic (usually conversational and streaming) because it can reduce packet error rate without increasing delays like ARQ.
- **Fragmentation module (FRM)**: Can decide on the recommended fragment length based on channel conditions.
- **IP Header Compression module (HC)**: This module can be used to reduce the overall header overhead, leading to increase of the available bandwidth.
- **SNOOP module (SNP)**: Snoop [6] is a popular performance improvement method for TCP, and as such it can also be used in the case of WAL.
- **QoS module**: Used to prioritise traffic, in order to maintain delay constraints, especially of real-time traffic.

This set of modules are interconnected and combined together so as to improve the level of QoS provision for a specific type of IP traffic. In this respect, the operation of the WAL can be summarized as follows:

i) Each IP packet entering the WAL is classified to the corresponding WAL association.
ii) After classification, the WAL Coordinator forwards the incoming packets to the first module of the corresponding WAL module chain.
iii) Each module in the chain performs its corresponding action on the packet (e.g., FEC module adds CRC bytes), and returns the packet to the WAL Coordinator that passes it to the next module in the chain. At the receiving side the packet traverses the module chain in the reverse order.

The parameters of each module are set so as to optimise the system performance under the current channel conditions and the volume of traffic. In order to adapt to the changing channel conditions or user requirements (in terms of QoS level, or requested bandwidth) the parameters of each module can be set dynamically.

In order to interface with a number of wireless drivers of different wireless technologies (such as IEEE 802.11, Bluetooth, HiperLAN/2, etc.), WAL makes use of one Logical Link Control Translator (LLCT) module for each different wireless technology. The main functions of this module manage the connection status with the wireless driver, and ensure the stream conversions toward the wireless driver. A more detailed description of the WAL can be found in [4].

An important aspect of the WAL operation is the classification of incoming IP traffic to the appropriate WAL classes. The classification scheme proposed for WAL is based on the Differentiated Services (DiffServ) architecture [7]. According to the DiffServ model, IP traffic entering a network is classified and possibly shaped and conditioned at the boundaries of the network, and assigned to different behaviour aggregates. Each behaviour aggregate is identified by a single 8-bit DiffServ code point (DSCP), contained in the IP header [8]. Within the core of the network, packets are forwarded according to the Per-Hop Behaviour (PHB) associated with the DSCP. The main advantage of DiffServ architecture is that it achieves scalability, since state information for per-application flows or per-customer forwarding discipline does not need to be maintained within the core network.

One of the most promising PHBs that have been proposed within IETF, is Assured Forwarding (AF) [9]. The AF PHB provides delivery of IP packets in four, independently forwarded, AF classes. Within each AF class, an IP packet can be assigned one of three different levels of drop presence. So there are four classes with three different drop probabilities each. Therefore, twelve DSCPs have been reserved for this PHB group.

	Class 1	Class 2	Class 3	Class 4
Low Drop	001010xx	010010xx	011010xx	100010xx
Medium Drop	001100xx	010100xx	011100xx	100100xx
High Drop	001110xx	010110xx	011110xx	100110xx

Table 1. Recommended codepoints for the AF PHB (xx=currently unused)

All other DSCPs not belonging to AF PHB group can be mapped to the default PHB (DSCP = 000000XX) which corresponds to the standard Best-Effort Service.

The proposed approach for the WAL makes use of the AF PHB in order to classify the IP flows and provide a different service to each traffic class. In this approach, each type of application is mapped to one of the four main classes of AF PHB. We identify 4 types of applications:

- **Conversational** (e.g., Voice over IP, Tele-conference)
- **Streaming** (e.g., Video/Audio streaming)
- **Interactive** (e.g., Web Browsing)
- **Best effort** (e.g., Mail, Telnet, FTP)

These types of applications are mapped on the AF/Default PHB DSCPs and classes as shown in Table 2.

Application Type	DS CodePoint	Class
Conversational	(001)010XX (001)100XX (001)110XX	AF I
Streaming	(010)010XX (010)100XX (010)110XX	AF II
Interactive	(011)010XX (011)100XX (011)110XX	AF III
Best effort	(100)010XX (100)100XX (100)110XX	AF IV
	000000XX	Default PHB

Table 2. Mapping of Application Types to AF/Default PHB DSCPs and Classes

For each traffic class, the WAL utilizes a different WAL module chain. Each WAL chain consists of a number of WAL modules that are interconnected and combined together so as to improve the level of QoS provision for a specific type of IP traffic. The possible set of module chains for the aforementioned classes is shown in Figure 2. Note that for AF III and AF IV/Default classes two alternative module chains are proposed. The second ones (those including the SNOOP module) can be utilized only for TCP applications. TCP data flows can be recognized by the Protocol Type field of the IP header. Note also that the QoS module is always present and last in every module chain. QoS performs packet scheduling within WAL, hence it is put last in the chain so as to guarantee that the scheduled packets will be ready for transmission and will not experience any further delays within WAL due to processing or queuing in other modules.

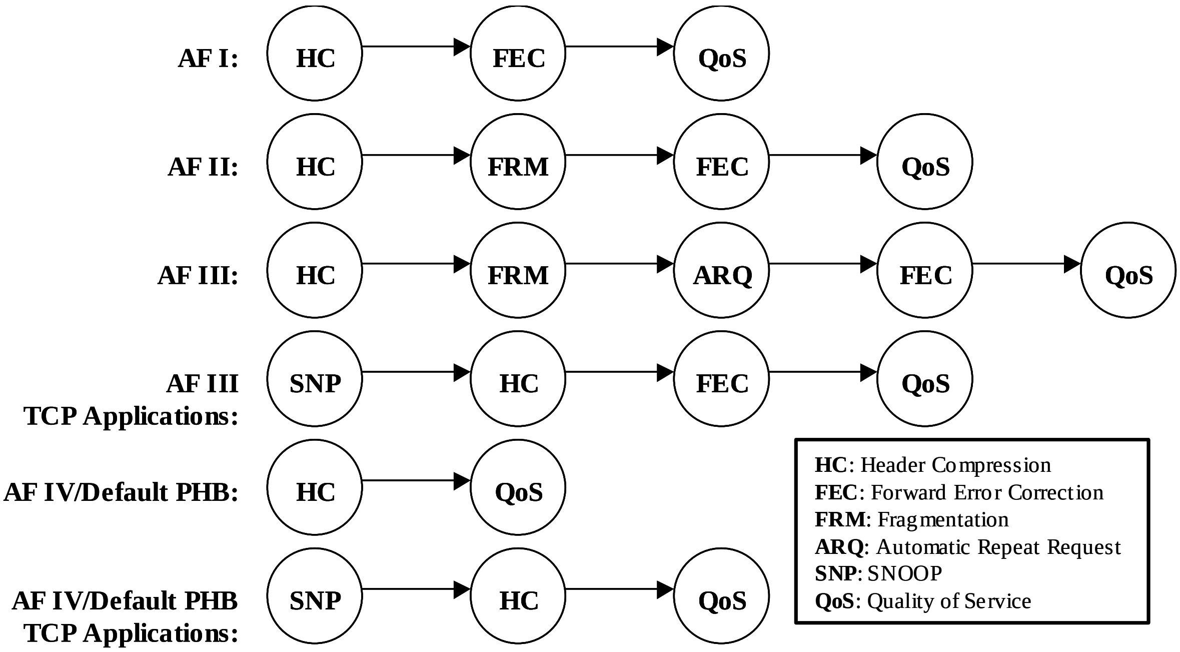


Figure 4. Proposed Module Chains for each traffic class in WAL

3. WAL and MHWN

The idea of extending the use of the WAL in MHWN is based on the fact that the WAL provides a transparent, uniform and consistent QoS mechanism that is independent of the underlying wireless technology. These features are important in MHWNs because they reduce the interoperability issues among the various technologies to the minimum, thus facilitating the communication between devices from different vendors and technologies. At the same time, QoS is handled in a uniform way across all nodes of the MHWN. This allows the development of a QoS mechanism that is efficient, scalable and easily adaptive, and allows network elements to dynamically enter or leave the network.

The proposed MWHN protocol stack, incorporating the WAL is shown in Figure 5.

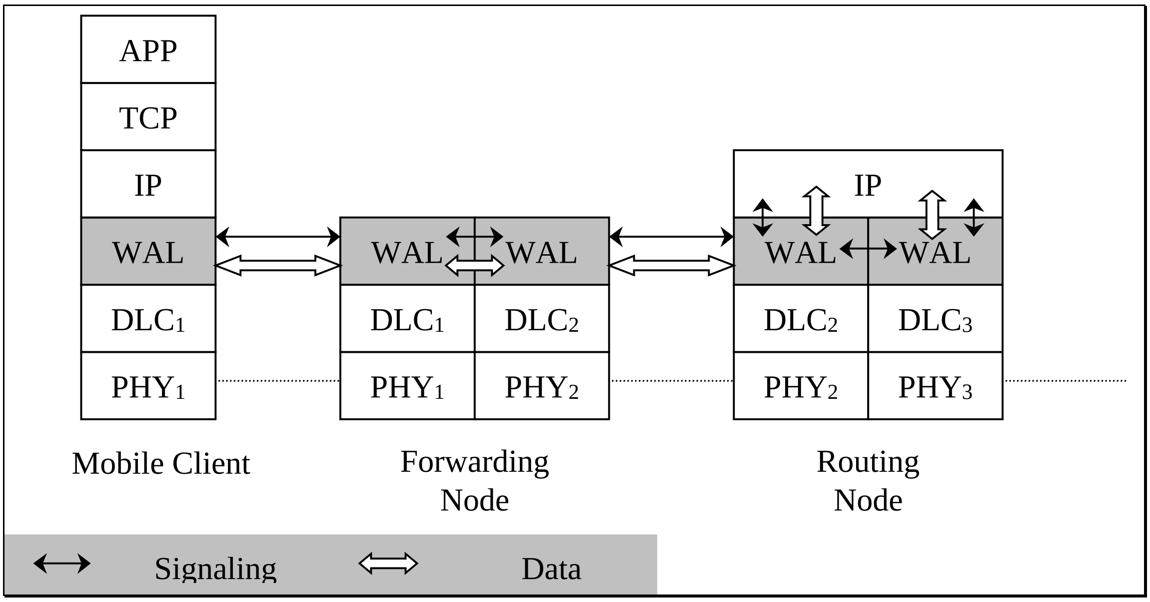


Figure 5. MHWN protocol stack incorporating theWAL

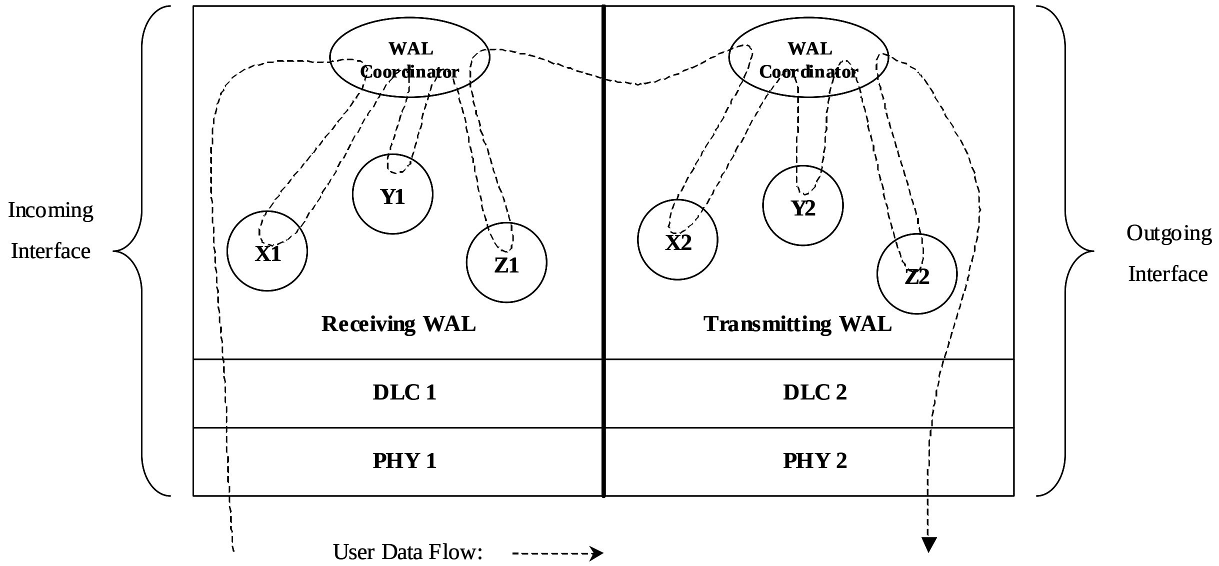
As shown in this figure, three kinds of nodes are identified in a MHWN. The Mobile Client (MC) is the node wishing to use an Internet Service over a MHWN (see also Figure 1). The Forwarding Node (FN) is an intermediate node that is used as a bridge to interconnect the MC with a Routing Node (RN). The RN bears an IP layer and thus it has IP routing capabilities while the FN bears no IP layer and is just configured to forward the traffic from specific input to specific output interfaces without performing any kind of routing. It is possible that zero or more than one FNs are interposed between the MC and the RN.

Both the FN and the RN support multi-mode operation and for this reason they incorporate different protocols stacks at the DLC and PHY layers, one for each mode (technology). For simplicity reasons, in Figure 5 we present dual-mode nodes.

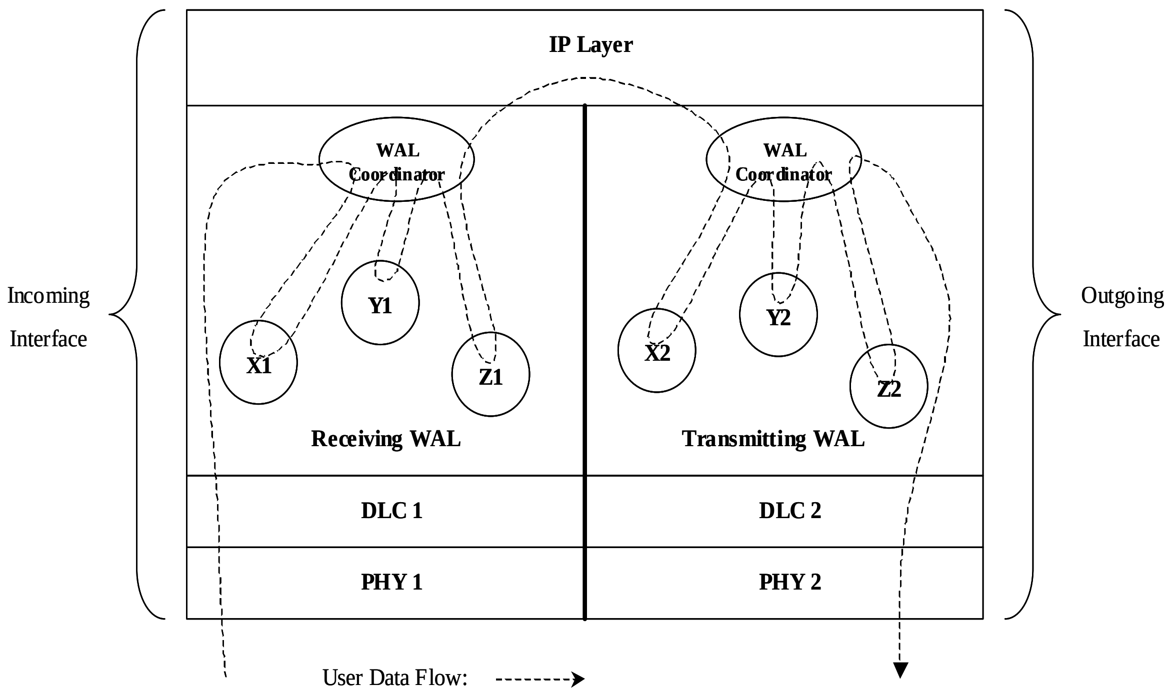
The WAL appears at the protocol stack of all referenced nodes. The FNs and RNs have one instance of the WAL for each input or output interface. At the FNs every incoming packet is handled by the receiving WAL instance and then is passed directly to the transmitting WAL instance that forwards it to the next node. At the RNs, the receiving WAL instance forwards the user data to the IP layer, where they are routed and then they are passed to the transmitting WAL instance. In every WAL instance, each packet may be passed through different WAL module chains (or through identical module chains but with different module parameters) depending on the classification in the corresponding interface and the channel and traffic conditions in that interface.

The establishment of new WAL associations along a multi-hop path is performed in a per-hop basis. In the RNs, upon arrival of a WAL frame, the receiving WAL instance, after performing all necessary operations (traversing of the corresponding module chain) forwards the IP packet to the IP layer. The IP layer performs routing, determines the outgoing interface through which the packet should be forwarded to and passes the packet to the corresponding transmitting WAL instance. In th FNs, on the other hand, the receiving WAL instance performs again all the necessary operations and then, based on the forwarding configuration of the node, determines the outgoing interface through which the packet should be forwarded. Then it forwards the IP packet directly to the corresponding transmitting WAL instance.

When the packet arrives at the transmitting WAL instance, the transmitting its class and the corresponding WAL chain is determined (based on the classification scheme used). If no association corresponds to this packet (i.e., it is the first packet of a new association the transmitting WAL triggers the establishment of a new association. If the establishment is successful, the transmitting WAL instance passes the packet through the WAL chain and forwards it to next node.



(a)



(b)

Figure 6. User Data Flow at the FNs (a) and RNs (b)

An important requirement for the smooth operation of all WAL instances along a multi-hop path is that all WAL instances use the same classification scheme of incoming IP packets. In this way, all nodes in the path intercept the QoS requirements in the same way. Of course, it is possible that in each hop these requirements are fulfilled in a different way (e,g,. utilization of differerent module chains or parameters for the same class along two different hops), but the QoS level provided for each class should be the same along all hops in the path.

Figure 6a and Figure 6b show the user data flow in the case of FNs and RNs. Observe that in both cases, at the incoming interface user data traverse the WAL module chain that correspond to their association (modules X1,Y1 & Z1) within the receiving WAL instance. Then data are passed to the Transmitting WAL instance either directly (FNs) or through the IP layer (RNs). In the transmitting WAL instance, the user data traverse the module chain that corresponds to their new association (modules X2, Y2 & Z2) and, eventually, are forwarded through the outgoing interface to the next node.

4. Conclusions – Future Plans

A novel QoS support scheme for MHWNs based on the concept of the WAL was presented. The WAL is an intermediate layer between the DLC and IP layers aiming to provide improved performance in a wireless IP environment. In MHWN environments, the WAL can be used to provide QoS support and compensation for link quality variations and interference.

The WAL operates transparently to both the upper and lower layers, thus it does not require any modifications or enhancements to the existing technologies. QoS in the WAL is based on the concept of WAL Associations. Each data packet entering WAL is appropriately classified to a WAL Association. Each WAL Association utilizes a WAL module chain consisting of several modules that can be combined together and improve the QoS level.

The solution presented here, proposes the use of different WAL instances at the forwarding and routing nodes of a MHWN. Each WAL instance corresponds to one wireless interface of the node. In each node, user data are passed from the one WAL instance to the other, either directly or through the IP layer. The two WAL instances guarantee that each data packet will receive the same treatment in terms of QoS in both wireless hops that each intermediate node is involved.

Future plans of this work include the detailed description of the WAL operation in a MHWN environment (signalling, primitives, parameters) as well as the development of a simulation model that will be used to extract measurements regarding the improvement of QoS level that can be achieved with the use of WAL in a MHWN.

Acknowledgments

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