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A MAC Layer Abstraction for Heterogeneous Carrier Grade Mesh Networks

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Abstract: Providing carrier grade services to a large number of mobile users is becoming an important challenge for wireless network operators. One promising solution for offering cost-efficient alternatives compared to classical cellular approaches is the use of wireless mesh networks along with the use of heterogeneous radio technologies. In this paper we propose a MAC abstraction layer to lessen the management burden of heterogeneous radio technologies. This abstraction layer is intended to hide the complexity and specifics of different wireless interfaces, this way supporting the use of a single set of routing and capacity handling mechanisms.

Keywords: Mesh networks, Carrier grade, Media Access Control, Abstraction layer

1. Introduction

Recent advances in technology have made mobile devices affordable for almost everybody suitable for rich mobile applications. Owing to this, the interest of mobile Internet users is continuously shifting from pure voice communications towards high rate data services as high quality multimedia applications and online gaming. Providing wireless access for these types of services to a large amount of users at a satisfactory quality is a costly endeavor. It is foreseen that existing cellular network architectures will not be able to accommodate the arising demand [1]. A promising alternative solution for offering wireless access, at least in non-urban environments and for temporary usage scenarios are the wireless mesh networks (WMNs) [2].

As compared to current cellular access technologies, which heavily rely on hidden but complex infrastructures, mesh networking provides a cost effective alternative for realizing backhaul networks. This owes to the multi-hop architecture of wireless mesh networks enabling them to cover large areas without requiring each base station to be directly connected to the core infrastructure (CapEx). Furthermore, WMNs are expected to intrinsically support self-organization and self-optimization taking changing wireless conditions into account. This self-optimization features result in lower network maintenance costs for the network operators (OpEx).

Current deployments of mesh networks, e.g., Roofnet [3], are typically based on a single radio technology, generally IEEE 802.11. Despite the benefits in terms of a clear network management, choosing a single radio technology has drawbacks on efficient and cost-effective deployments. The major drawback probably is that it prevents from exploiting the strengths of different radio technologies in different environments, e.g., for indoor vs. outdoor or short vs. long-range sections of the mesh network. However, supporting multiple types of radio interfaces may introduce a significant management burden, severely reducing the benefits of the mesh network approach. In this paper we present an architecture that tackles this challenge by designing an abstraction layer to hide most of the complexity of the radio interface management. This architecture is being developed by the EU FP7 project CARMEN "CARrier grade MEsh Networks" [4].

The remainder of this paper is organized as follows. Section 2. presents the CARMEN architecture and its key comprising elements. Section 3. describes in detail the proposed MAC abstraction layer, including a use case example. Finally, Section 4. summarizes the paper and exposes the directions of the future work.

2. A Carrier Grade Mesh Architecture

The CARMEN architecture aims to specify a WMN solution for providing triple-play operator services while supporting ubiquitous end-user connectivity and using a heterogeneous technology backbone. Different wireless technologies provide different tradeoffs in terms of capacity, range, robustness, and costs. It is therefore envisaged that an operator's network will naturally comprise a mixture of complementary technologies. Currently, two of the most compelling wireless technologies are WiFi and WiMAX. These technologies can be selectively combined to realize a variety of heterogeneous mesh backhaul solutions that suit different requirements in terms of usage or deployment.

The key CARMEN objectives are: guaranteeing carrier-grade services, making an efficient use of the radio resources, supporting mobility, broadcast and multicast services, and self-configuration. The CARMEN mesh provides end-users with carrier-grade access to communication services. The user terminals (UTs) are expected to be conventional devices with IEEE 802.21 support for mobility, while the core network is an IP-based infrastructure. Figure 1 depicts a typical CARMEN network topology introducing all types of CARMEN nodes. These are

- CARMEN Mesh Points (CMP). A CARMEN Mesh Point is a node within the CARMEN mesh that is equipped with CARMEN capabilities. CMPs forward traffic to and from the UTs being conscious of QoS requirements. A CMP may have one or more radio interfaces of different technologies, including IEEE 802.11 [5], IEEE 802.16 [6] and DVB [7].

- CARMEN Access Points (CAP). A CAP is a CMP with the ability of providing UT access to the CARMEN mesh. The set of radio technologies employed on the access links may be different from those used within the CARMEN mesh.

- CARMEN Gateways (CGW). A CGW is a CARMEN mesh point that provides connectivity to the network provider's core network.

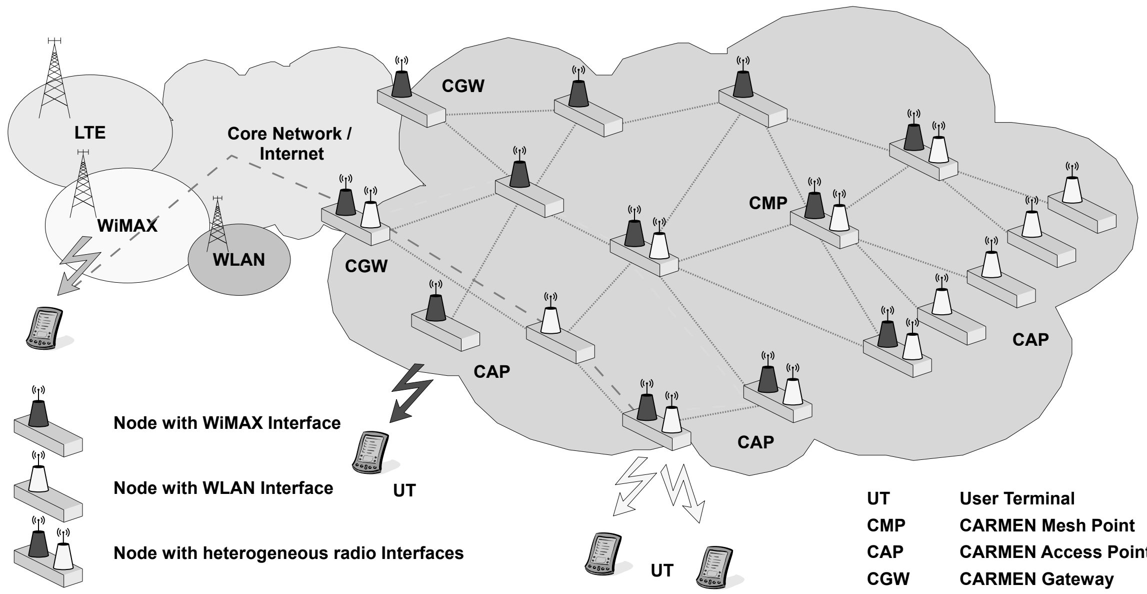

Figure 1: Network topology example

All the mesh network nodes may use heterogeneous wireless interfaces to communicate among them. To lessen the management complexity of such heterogeneity, e.g., for routing optimization, the CARMEN architecture relies on an abstraction layer to provide a common interface on top of the radio technologies. This MAC abstraction layer is detailed in what follows.

3. The CARMEN MAC Abstraction Layer

Figure 2 depicts the node architecture of a CARMEN Mesh Point. The *CARMEN layer* of all mesh-relevant building-blocks is structured into two sub-layers: the *MAC Abstraction sub-layer* and the *Mesh Functions sub-layer*. The CARMEN Mesh Functions sub-layer includes all mechanisms and algorithms needed for setting up a mesh topology and coordinating the mesh nodes to perform advanced functions such as *routing (RtF)*, *mobility management (MMF)*, *capacity handling (CHF)*, *monitoring*, and *self-configuration (SCF)*. These mesh functions are organized in modules which interwork with each other locally or remotely via interfaces.

The MAC Abstraction sub-layer has a scope of single wireless hops and consists of two parts: (1) a *technology independent part (TIP)* and (2) a *technology dependent part (TDP)*. The separation between the technology dependent part and the technology independent part is with respect to the type of information they handle. The Interface Management Function IMF in the TIP hides the complexity and specifics of each technology providing a common set of functions to the upper modules implementing the network wide mesh functions. This common interface is named *Abstract Interface (AI)* and incorporates part of the IEEE 802.21 [8] media independent handover features, but also provides additional means to support mesh-specific requirements.

Inside the CARMEN MAC Abstraction sub-layer, different wireless technologies are linked to the CARMEN AI by *MAC Adapters* being the mappers between the technology dependent part and the technology independent part. The attachment of MAC Adap-

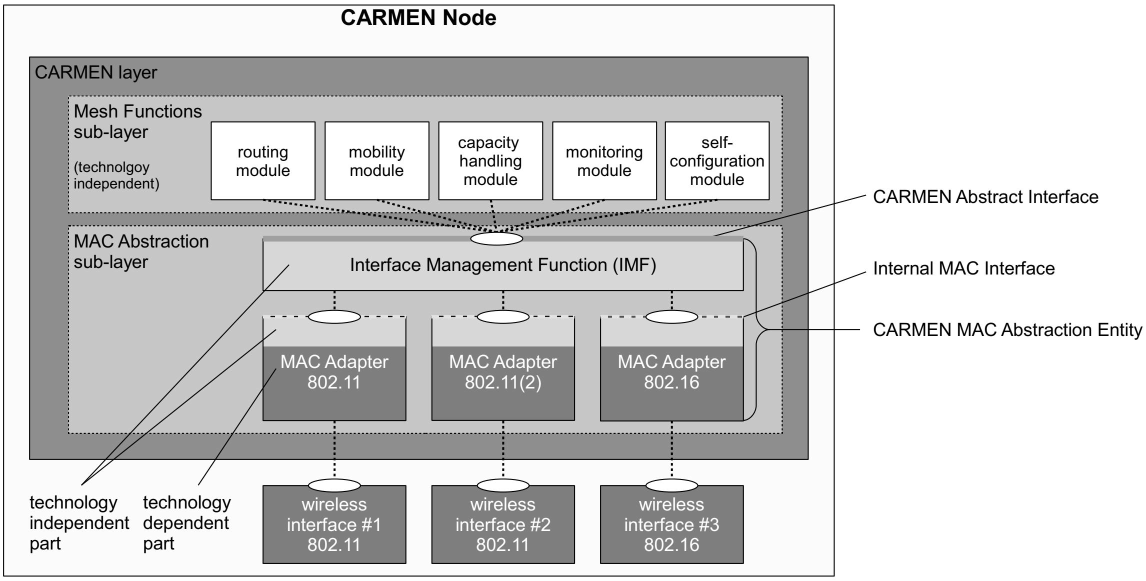

Figure 2: The sub-layers and building blocks of a CARMEN Mesh Point

tors to the Interface Manager will be realized by an internal interface implementing most of the service primitives and using the same information representation as the CARMEN Abstract Interface.

From a prototype system point of view, the technology dependent part of the MAC Abstraction sub-layer, i.e., the MAC Adapters, have to be installed and instantiated according to the presence of wireless interfaces of the CARMEN node. The technology independent mesh functions and the IMF are intended to be identical for all mesh nodes and may only differ slightly depending on the type of CARMEN node, i.e., whether it is a CMP, CAP, or CGW. This difference is rather behavioral in the sense that some of the mesh function modules may or may not be part of a node type or could act differently if the CARMEN node is connected to the backbone, it embeds AP functionality, or it is simply a mesh point.

The MAC Abstraction sub-layer will operate both at data and control plane, providing means for media access and traffic forwarding considering QoS requirements, as well as support for mobility management and self-configuration of the radio interfaces. These features are detailed next.

3.1 Data Plane

CARMEN aims to implement a forwarding solution with extended functionality on top of the existing implementations of the forwarding module in current operating systems. This is in order to avoid adding up complexity and rather focus on adding carrier grade features. This implies that the standard interfaces and protocols between layer 3 and layer 2 will be left unmodified. Therefore, the IPv4/IPv6 addressing schemes, standard address resolution protocols ARP/NDP and control message protocols ICMP/ICMPv6 will be part of the protocol stack in every CARMEN node, as this is shown in Figure 3.

Traffic in the CARMEN backbone will be carried through pipes. A pipe consists of the aggregation of multiple user flows with similar end-to-end requirements and will be created at the ingress and egress nodes, along with a unique label, i.e., the pipe ID. The

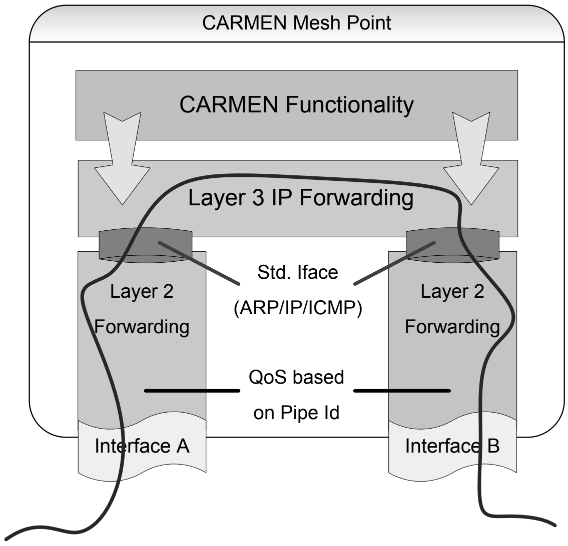

Figure 3: Forwarding model

Routing Function of CARMEN will ensure that the forwarding tables are configured such that traffic aggregates are forwarded to the next hop based on the required QoS constraints. To implement the pipe ID system, two solutions are under study, namely MPLS labels and IPv6 Flow Label field.

At intermediary mesh points, incoming packets will be decapsulated, passed through the look up process and delivered to the appropriate interface towards the next hop. The outgoing interfaces will encapsulate the packet in the specific data link technology. The MAC abstraction layer will enable performing resource allocations and priority based queuing in order to meet the QoS allocations previously done. It will map the pipe IDs to 1-hop QoS allocations and will schedule the packets according to their requirements.

3.2 Control Plane

The CARMEN node architecture adopts the general IEEE 802.21 architecture [8] extending it to meet the requirements posed by the mesh topologies. The main difference between IEEE 802.21 and the CARMEN MAC Abstraction layer lies within their scopes. While IEEE 802.21 mainly focuses on providing means to perform a seamless handover between heterogeneous technologies, CARMEN extends the IEEE 802.21 concept in order to globally manage a mesh network including heterogeneous wireless technologies.

The primitives implemented by the abstraction layer comprise event notifications, commands and information service. The function set of the CARMEN Abstract Interface extends the IEEE 802.21 Media Independent Handover Function (MIHF) beyond its original purpose to include QoS, self-configuration, routing and spectrum management support. This is achieved also by a close interaction with the CARMEN monitoring system that resides below and above the IMF and provides the means to have timely information about the wireless links, which is of significant importance when aiming to provide optimal usage of the mesh resources.

3.3 Use Case Example

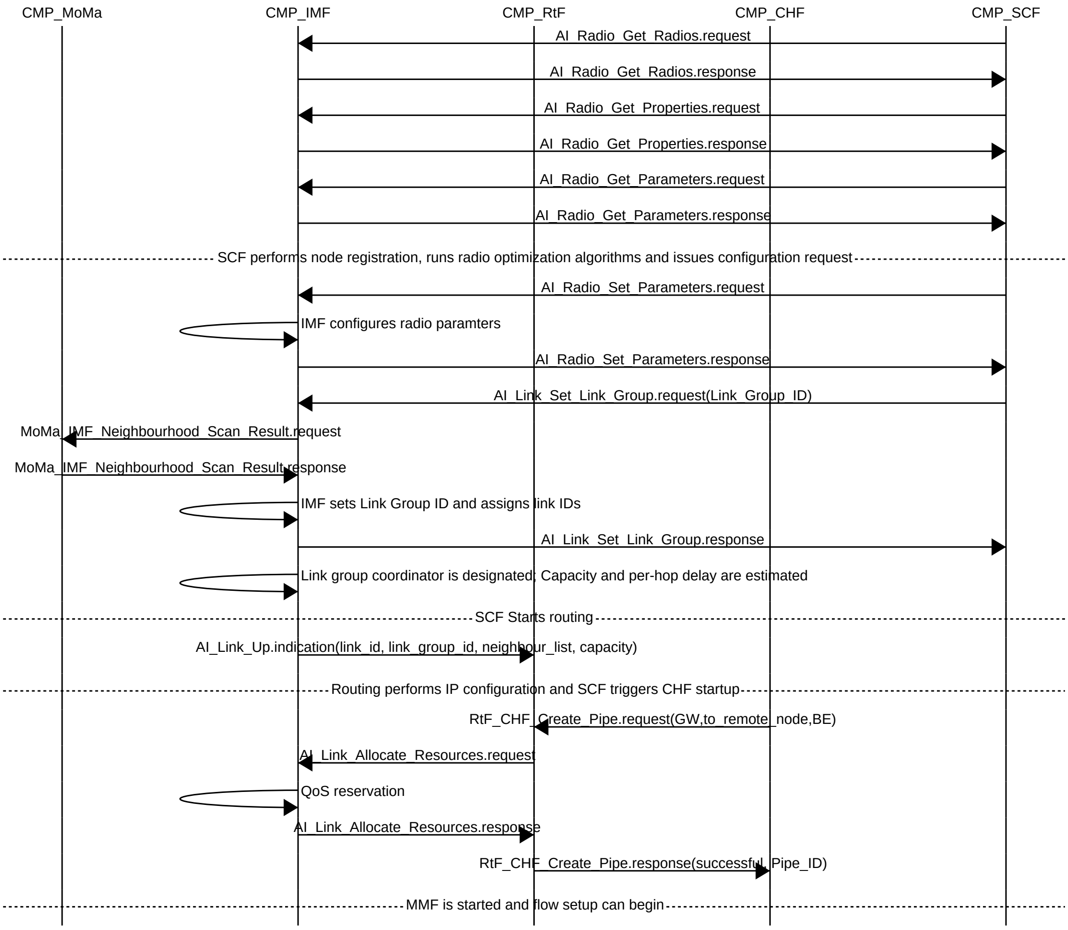

Figure 4: Message sequence chart for the bootstrap phase

In order to better illustrate the functionality provided by the IMF through the CARMEN Abstract Interface, we now present the node bootstrap as an example use case. The goal of the bootstrap process is to configure the wireless interfaces of all nodes so that at the end of the bootstrap phase any node is aware of its neighbors and is able to perform forwarding of mesh traffic as well as handling new pipe requests. The node setup depends on parameters provided by the self-configuration function taking link properties like the effective capacity of a shared link and foreseen delay bounds into account. Furthermore, initial QoS allocations for mesh internal signaling are made. The process is detailed by the message sequence chart depicted in Figure 4.

A node begins its bootstrapping once it is turned on, by first detecting its capabilities. The Abstract Interface provides a set of primitives (*AI_Get_Radios*, *AI_Radio_Get_Properties* and *AI_Radio_Get_Parameters*) that allow the self-configuration module to gather information of each radio interface, e.g., about the technology used, the physical addresses used, the sensitivity range, and the antenna properties. Once the information about the mesh topology is available through the use of measurement modules, self-configuration will run the radio optimization algorithms to provide the best configuration found in terms of radio channels, power levels and modulation schemes to be used. The AI also provides the necessary primitives for performing the radio parameters setup (*AI_Radio_Set_Parameters*). Additionally, SCF provides a unique identifier for the shared links. Upon completing this phase, *Link_Up* events are issued to inform routing function about the availability of the newly configured links. The indicated primitives will provide the previously mentioned identifiers, the list of neighbors and the report on available capacity. After the capacity handling function is started it will attempt to perform the first QoS reservations in order to setup best-effort pipes for basic communication. This is supported by the AI through the *AI_Link_Allocate_Resources* primitives. The bootstrap phase completes after the mobility management function is started and new flows can be admitted in the network.

4. Summary and Future Work

In this paper we presented a novel architecture for carrier class WMNs hiding the complexity of heterogeneous radio interfaces by introducing a MAC abstraction layer. This abstraction layer is located between the wireless devices and the upper layer mesh modules, which are for routing, mobility management, capacity handling, monitoring, and self-configuration. Following this approach, it is expected to reduce the management complexity of heterogeneous wireless mesh networks. Furthermore, it is envisaged to support per-hop quality of service management allowing the overall mesh network to be predictable in terms of user observable performance measures. Preliminary cost analyses promise that wireless mesh networks can lead to noticeable cost reductions of up to 50% depending on the considered environment.

Even if the use of abstraction layers is not entirely new, e.g., as this is proposed in the DAIDALOS project [9] in the context of future 4G networks, previous solutions were not specifically designed for the case of wireless mesh networks. In contrast to these approaches, the CARMEN proposal explicitly addresses the carrier class WMN requirements in order to achieve a reduced management complexity, to support QoS features, and to facilitate the use of self-management, recovery and reconfiguration mechanisms.

Future work will refine the design of this MAC abstraction layer and will focus on system evaluations. The proposed CARMEN system architecture including the MAC abstraction layer will be assessed against classical cellular systems in terms of efficiency and costs. For system evaluations, simulations and testbeds are under development. The CARMEN testbed will implement various wireless technologies, such as IEEE 802.11, WiMAX and DVB.

Acknowledgements

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