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# Topology forming and optimization framework for heterogeneous wireless back-haul networks supporting unidirectional technologies

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ABSTRACT

Wireless operators, in developed or emerging regions, must support triple-play service offerings as demanded by the market or mandated by regulatory bodies through so-called Universal Service Obligations (USOs). Since individual operators might face different constraints such as available spectrum licenses, technologies, cost structures or a low energy footprint, the EU FP7 CARrier grade wireless MEsh Network (CARMEN) project has developed a carrier-grade heterogeneous multi-radio back-haul architecture which may be deployed to extend, complement or even replace traditional operator equipment. To support offloading of live triple-play content to broadcast-optimized, e.g., DVB-T, overlay cells, this heterogeneous wireless back-haul architecture integrates unidirectional broadcast technologies. In order to manage the physical and logical resources of such a network, a centralized coordinator approach has been chosen, where no routing state is kept at plain WiBACK Nodes (WNs) which merely store QoS-aware MPLS forwarding state. In this paper we present our Unidirectional Technology (UDT)-aware design of the centralized Topology Management Function (TMF), which provides a framework for different topology and spectrum allocation optimization strategies and algorithms to be implemented. Following the validation of the design, we present evaluation results using a hybrid local/centralized topology optimizer showing that our TMF design supports the reliable forming of optimized topologies as well as the timely recovery from node failures.


## 1. Introduction

Research on Wireless Mesh Networks (WMNs) has matured in recent years and Quality of Service (QoS)-support has been widely discussed (Kone et al., 2007; Wushi et al., 2008; Akyildiz and Wang, 2009). However, the applicability of the proposed WMN or Multi-Radio Wireless Mesh Network (MR-WMN) solutions for QoS-sensitive operator back-haul networks providing *triple-play* services is still actively being discussed. Compared to the traditional, rather statically planned and configured operator back-haul networks, meshed wireless back-haul networks offer simplified deployment processes due to their flexible self-configuration and self-management characteristics (Mihailovic et al., 2009). These enable them to quickly form optimized topologies and to adapt to usage pattern or wireless spectrum availability variations. For example, our heterogeneous Wireless Back-Haul (WiBACK)[1] architecture, which is based on the consolidated outcomes of the CARMEN (Banchs et al., 2008) project, supports the proper configuration of heterogeneous technologies, such as packet-switched IEEE 802.11, 802.16 or 802.22 equipment, or broadcast technologies such as DVB-T. Moreover, it also integrates existing technologies such as micro-wave or fiber-optical solutions.

Hence, for each deployment scenario, the most suitable technologies may be combined to optimally utilize the available spectrum resources in order to reliably provide back-haul capacity. The selection criteria may be requirements to operate in certain frequency bands, to support low per-node energy footprints, to support rapid temporary deployments or CAPEX/OPEX cost-effectiveness. For example, to address deployment scenarios in rural areas or emerging regions, low-power embedded devices with properly configured IEEE 802.11 radios may be used (Henkel et al., 2011; Kretschmer et al., 2011). Another scenario identified by the CARMEN project is the temporary extension of existing wireless coverage to address high demand periods due to special events such as the London Olympics (CARMEN-Consortium, 2009). This use case assumes an increased demand for live broadcast content, which can introduce a high load on capacity-constrained and especially on collision-sensitive wireless links (Fig. 1).

To address this issue, the WiBACK architecture integrates broadcast technologies, such as DVB-T, to enable the network

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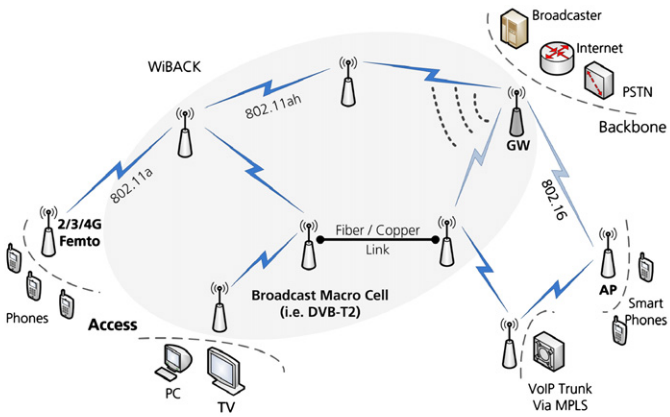


**Fig. 1.** The WiBACK architecture integrates heterogeneous technologies supporting mobile/fixed terminals and trunked payload.

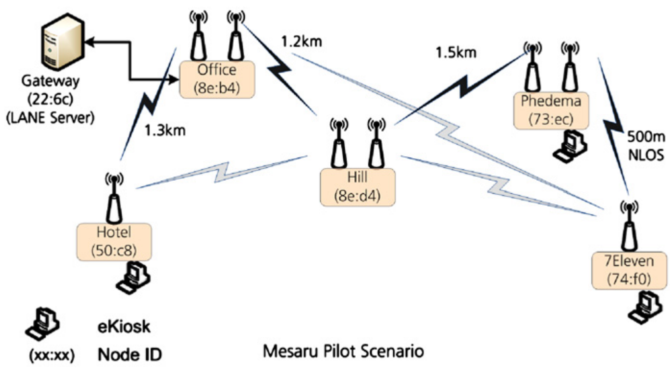


**Fig. 2.** The back-hauling pilot in Maseru, Lesotho consists of five outdoor WiBACK nodes and one indoor node acting as the WiBACK controller and GW node.

management components to dynamically route such traffic via more efficient broadcast technologies, possibly depending on customer demand, density and distribution. This allows the WiBACK architecture to leverage the existing broadcast infrastructure, exploiting the benefits of the usually longer range of broadcast cells and their higher channel utilization efficiency compared to typical, e.g., packet-based, IEEE 802 technologies.

The scope of our WiBACK architecture is to provide or extend existing back-haul capacity, which might range from single-hop long distance wireless connectivity to multi-hop connectivity with up to 10 hops in urban and rural environments in developed or emerging regions. The interface to external networks at Gateway (GW) or Access Point (AP) nodes can be realized via, e.g., regular Internet Protocol (IP), Proxy Mobile IP (PMIP) (Gundavelli et al., 2008), LAN Emulation (LANE) (Laubach and Halpern, 1998) or Multi-Protocol Label Switching (MPLS) trunking, see Fig. 1. As depicted in Fig. 2, a typical real-world back-hauling pilot scenario implementing our QoS-aware LANE concept has been presented and thoroughly evaluated regarding QoS performance in Kretschmer et al. (2011). Here we roughly assume a 90/10 *best effort*/Voice-over-IP (VoIP) traffic mix and typical back-hauling traffic flows between the AP nodes and the GW. IEEE 802.11a radios were employed as the wireless technology.

Our WiBACK architecture is based on a centrally managed cross-layer concept which builds on a set of IEEE 802.21-inspired command and event services and hardware abstraction as well as technology independent MPLS-based Traffic Engineering (TE) and a model to address potentially shared wireless channel resources. In the WiBACK architecture, MPLS Label-Switched Paths (LSPs) are associated with per-hop resource allocation and referred to as *Pipes*. These are used as aggregates providing resource isolation among traffic classes as well as individual *Pipes* of the same traffic class. Building upon proven TE concepts and protocols, the WiBACK architecture is considered as an alternative for a rather statically configured and over-provisioned operator back-haul network. It must, therefore, meet similarly strict requirements such as guaranteed QoS differentiation, high availability and predictable behavior in high load situations in order to support the provisioning of the triple-play service mix today's customers expect. Thus, to manage such heterogeneous WiBACK networks, a Topology Management Function (TMF) is required to facilitate proper resource descriptions, reliable node discovery as well as association. Furthermore, it must provide a framework for topology forming and maintenance, a database of node, interface and link properties, as well as available wireless spectrum resources and provide access to *live* link monitoring statistics. This information should allow for different topology optimization strategies to be utilized depending on the intended optimization goals, such as highest reliability, highest capacity or lowest energy consumption. Moreover, to support TE-based capacity management, the TMF must work in close cooperation with the Capacity Management Function (CMF) (see also Fig. 4), which is tasked with managing the capacity of the links activated by the TMF by assigning capacity to *Pipes* or 1-to-N multicast Trees based on capacity requests from AP nodes. The details of the CMF are outside the scope of this paper, which, accordingly, focuses on the presentation of our TMF design for the WiBACK architecture.

The rest of this paper is structured as follows. First, we discuss related work and compare it against the TMF requirements, followed by a summary of relevant background information on the WiBACK architecture. We then present our approach of a centralized TMF. This is followed by a functional validation and evaluation results obtained in real and emulated scenarios. Concluding, we summarize our contribution and give an outlook on future work.

## 2. Related work

Topology discovery in WMNs is typically handled at the *Network Layer* by protocols such as Optimized Link State Routing (OLSR), batman (Sridhar et al., 2009), Dynamic Source Routing (DSR) Protocol (Johnson et al., 2007) or Ad hoc On-Demand Distance Vector Routing Protocol (AODV) (Perkins et al., 2003) or by, for example, batman-adv (OpenMesh.org, 2011) or IEEE 802.11s at the *Data Link* layer, with the latter typically relying on a reactive distance ad hoc vector routing protocol. With the exception of 802.11s, such protocols are unaware of the underlying wireless hardware properties. Having their history in fixed wired routing protocols, such protocols do not support topology forming via, for example, channel selection or transmit power adaptation, and therefore work under the assumption that the wireless interfaces have already been configured and that connectivity has been established, either manually or via a separate mechanism. Topology discovery, link monitoring and route computation are implemented in one monolithic protocol, while capacity allocations, monitoring or enforcement thereof cannot be supported conceptually. Moreover, hot-standby backup paths (Pan et al., 2005), which are often used in TE-based networks to support fast fail-overs in cases of link or node failures are not supported.

Traffic Engineering (TE) is concerned with performance optimization of operational networks with the goal to achieve efficient and reliable network operations while simultaneously optimizing network resource utilization (Awduche et al., 2002). Compared to a typical rather statically configured operator network, a major difference of the WiBACK architecture is the TMF which is tasked