



The CARMEN (CARrier grade MESH Networks) project enables the provisioning of carrier-grade services over wireless mesh networks comprised of heterogeneous radio technologies. It is a 3 year project (January 2008 – December 2010) partially funded by the EU and carried out by 8 European partners – 2 network operators, 2 equipment manufacturers, 1 research institute and 3 universities.

CARMEN technology supports a low cost and fast-to-deploy mesh access network including triple-play services for mobile and fixed network operators, thus achieving: i) a cost-effective mesh network architecture design that supports carrier grade services, ii) support for mobile unicast and broadcast services within a meshed network environment, iii) multi-technology support via an interface providing an abstraction of radio based MAC layers.

Media independent link interface

An API was developed which allows network bootstrapping, QoS management, radio configuration and link state monitoring using technology-independent commands and events. This greatly facilitates OAM&P in heterogeneous networks. An adapter per technology provides a mapping to technology-specific primitives.

Novel link capacity model

This model allows capturing effective link capacities in a technology-independent way. Capacity inter-dependencies of links (links operating with the same spectrum, time and code such as typically with P2MP interfaces) can be modeled as well. Mappings of the model to WiFi, WiMAX and a proprietary TDMA MAC are defined.

MAC enhancements for mesh networks

Enhancements have been designed both for contention and centralized MAC mechanisms. In order to provide hard delay guarantees in multi-hop networks, a centralized MAC scheme based on TDMA has been designed and evaluated. For contention based schemes, algorithms have been designed to map the QoS requirements of a mesh networks into the parameters of 802.11e.

Carrier-grade routing for mesh networks

The CARMEN routing is a centralized solution based on complete link state knowledge of the whole mesh. For route placement, it considers capacity constraints as given by the capacity model and is thus able to accommodate significantly more flows than other routing schemes.

Mobility

Mobility management has two domains, the core and the mesh domain. The former is based on standard PMIPv6, the latter is tailored to the CARMEN architecture and tight to the routing solution. Access signaling is based on IEEE 802.21, but handovers can be signaled with flow granularity, so target nodes can be determined based on both access and available mesh capacity.

Resource pre-allocation

Path provisioning in CARMEN is done based on pipes, which are MPLS LSPs with associated resources and bundle multiple user flows. Thus, admission control can be done locally at the ingress points as long as sufficient pipe capacity is available. Studies were done to determine optimal pipe sizes and conditions for pipe size changes.

Self-organized radio configuration

Radio configuration is done during network bootstrapping as well as later on demand (e.g. after load shifts or longer-term link quality changes). Radio settings are first determined locally per node with a focus on minimizing inter-radio interference, and then globally, focusing on maximizing throughput and connection stability.

Monitoring

Quasi-passive monitoring minimizing the transmission of extra frames is used. To support unidirectional links and 1-to-N multicast trees, a receiver-based feedback-free mechanism is proposed. Measurements can be aggregated in different time scales to be exploited for short-term (routing) or long-term (self-configuration) adaptations.

Architecture

All individual concepts and mechanism introduced above have been integrated into a consistent architecture. It defines the required functional components, how these are distributed in the mesh network across nodes and how they interact with each other.

Economical analysis

Mesh and non-mesh topologies were compared. In general, a lower overall cost, lower payback period and higher accumulated cash flow for mesh in a 5-year time frame was revealed. A sensitivity analysis for different mesh clusters and a non-mesh topology proved that both WiMAX and WiFi mesh clusters are not sensitive to equipment, site cost, site rental and gateway backhaul subscription cost.

The work conducted in CARMEN has been published in top conferences and journals in the field. A number of key concepts have been pushed into standardization to the IETF, IEEE, ETSI and NGMN, and in particular CARMEN members have played a key role in the creation of a new Study Group in IEEE 802.21 that focuses on media independent services. The results have been disseminated in various ways, including the two CARMEN workshops (collocated with the ICT Mobile Summit 2009 and IEEE INFOCOM 2010) and several demonstrations (including one at ACM SIGCOMM 2010). The industrial partners of the project have filed more than 10 patents resulting from CARMEN ideas, and one of them has set up a testbed in its premises where the project concepts are currently being evaluated.

Further information, a complete list of references and contact data is available at [http:// ict-carmen.eu](http://ict-carmen.eu).