# Enhanced Integrated IP/MAC/PHY Services for Ad hoc Networks

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***Abstract*— This demo presents a new wireless ad hoc network architecture that supports multi-hop communications efficiently. This architecture contains a cluster based MAC layer and a reliable PHY layer closely integrated. Link state routing tied to the MAC layer through a cross-layer interface to improve overall performances. We have implemented the architecture in software and ported it on an RT (Real Time) Linux platform equipped with a PCMCIA board containing an FPGA and two RF chains. We will demonstrate the equipment for audio and surveillance data applications through multi-hop communication.**

***Index Terms*— Ad hoc networks, cross-layer integration, software radio, communications system prototype**

## I. Introduction

Mobile Ad hoc NETworks (MANETs) [1] allow the rapid deployment of communication systems. In this context, the mobile nodes share one or more wireless channels without centralized control or established infrastructure. All nodes communicate directly with the ones within their transmission range and have routing capabilities to allow multi-hop communications. Application fields include setting up complementary hotspots for large events, extending cellular networks or rapid deployment of broadband hotspots for disaster and relief operations [2].

Because of the time-varying quality of the radio medium and the mobility of nodes, many challenges have to be faced in ad hoc networks to provide efficient network services to applications. To support efficient multi-hop networking, new architectures must be defined, focusing on cross-layer paradigms. In this work, we propose two levels of cross-layer integration, between PHY and MAC, and between MAC and IP layers.

In the MANET community, building ad hoc network prototypes has been acknowledged as key for validating simulation results. Most prototypes are built over legacy 802.11 cards, limiting assessment to routing and preventing the study of other MAC schemes than CSMA/CA mechanisms, a known bottleneck for the scaling of multi-hop networks [6]. The present prototype is based on the flexibility offered by software radio development, executed on a mixed General Purpose/ FPGA hardware architecture.

The proposed demonstration is focused on a scenario, showing a working IP/MAC/PHY stack that supports surveillance and audio services.

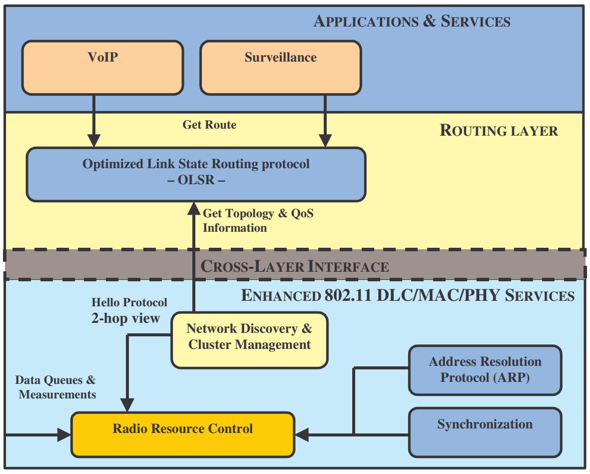


Fig. 1. The system architecture

The prototype implements a novel vertically integrated system architecture composed of the following components (Fig. 1):

- The enhanced 802.11 DLC/MAC/PHY services that provide reliable communication mechanisms to support synchronized transmission and QoS. It cooperates with the other components through the optimized *cross layer interface*.
- The Optimized Link State Routing (OLSR) [3] protocol is the basic routing component; this choice resulted from the analysis of mobility patterns, nodes density and traffic loads.

## II. MAC/PHY Overview

A more reliable MAC layer than the commonly used IEEE 802.11 MAC layer based on CSMA/CA is needed to support efficient ad hoc QoS features. Inspired by the IEEE 802.11e, 3GPP, and HiperLAN/2 standards, the importance of the co-design of MAC and PHY layer with cross layering and QoS support in mind is taken into account here. We provide a brief overview of this MAC/PHY layer; more details can be found in [7].

The network topology is organized (at the MAC layer) in 1-hop clusters as shown in Fig. 2. Cluster heads manage the radio resource within their clusters and are elected by a clustering algorithm selecting the nodes that have the maximum number of neighbors. In addition; radio-related parameters can also play a role in the election policy; for instance the transmit power and signal processing capabilities of different nodes. Relay nodes which are associated with more than one cluster allow communication between clusters in the event that cluster heads do not have direct connectivity but can still be synchronized. Note that at Layer 3, all nodes have the same capabilities but their roles are assigned dynamically.

The PHY layer provides high bit rate wireless links using OFDM(A) modulation (802.16x proposals, 3GPP HSDPA) with high-order QAM constellations. The timing and frequency synchronization is achieved with specially designed synchronization sequences periodically broadcasted by the cluster-head, which permit accurate simultaneous time offset estimation and carrier frequency tracking. Moreover, the signals will be designed to allow for adjacent clusters to synchronize to each other by ensuring time/frequency tracking over longer distances than those considered for transmitting data.

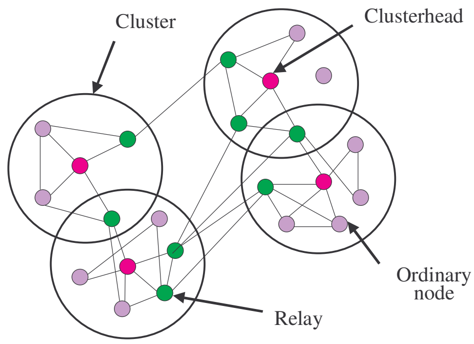


Fig. 2. Cluster organization at MAC layer.

The MAC/PHY layer combines opportunistic scheduling techniques and channel coding/ARQ in a single entity. The data units are scheduled without contention according to QoS levels and physical resources (i.e. frequencies, antenna, and time slots). This indicates that the resource allocation is done at the MAC allowing for rapid response time. The MAC/PHY layer is multi-user/stream capable (in contrast to IEEE 802.11 legacy) due to time-frequency slotted nature of the channel and the OFDM(A) characteristics. Roughly speaking this architecture is an extension of the 802.11e specifications. The primary extensions are:

- Multi-user capabilities (OFDMA and spatial multiplexing).
- Mechanisms for QoS management.
- A rapid measurement feedback channel for channel states and queuing information allowing for hard-QoS support.
- Synchronization mechanisms for multi-network (multiple cluster-heads) operation.
- Enhanced link quality information in support of the network layer routing protocol.

## III. MAC/IP INTEGRATION

Routing is carried out by one of the MANETS protocol, the Optimized Link State Routing (OLSR) protocol. OLSR is an augmented version of a pure proactive link-state protocol specially designed for ad hoc networks. It has been strongly optimized to reduce the network overhead induced by control traffic. In the work presented in this demo, the IP and MAC layers are closely integrated as shown by Fig. 3.

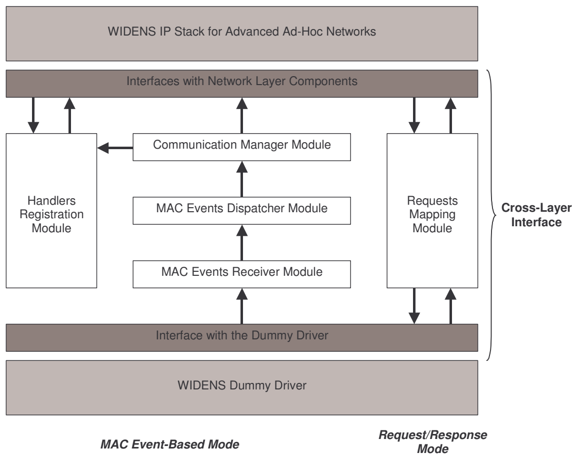


Fig. 3. IP/MAC cross-layer design.

Such an IP/MAC cross-layer design allows to provide not only optimizations to ad hoc routing protocols but also faster reactivity. For instance, classical routing protocols, like OLSR, implement link sensing and neighbourhood detection features. But detecting neighbour nodes and finding or losing a link to one of them using a network layer mechanism implies always a significant delay. Moreover, usually these mechanisms are implemented twice: once at the MAC layer and another once at the routing level. Therefore, the OLSR protocol can be optimized in order to no longer uses HELLO packets but gather neighborhood information directly from the MAC layer using a specific cross-layer design. This design enables the routing protocol to react better and faster to network dynamic.

This tight interaction between routing and MAC is completed by a QoS framework relying on scheduling at the MAC layer (with four classes as defined in the 802.11e specifications), and ensuring a per-class signaling by applications (similar to DiffServ mechanisms).

IP and MAC layer integration is achieved through the cross-layer Interface (See Fig. 3). This interface is implemented as a Linux driver and offers two main mechanisms to access MAC layer information:

- A MAC event-based mode (i.e. unsolicited information), allowing fast reaction to network information and resources changes;

- A request/response mode (i.e. solicited information), allowing direct access to MAC information and resources.

The main benefits of this integration are:

- Avoiding replicating information requests at different layers (e.g. 1-hop or 2-hop neighbors)
- Faster reaction to changing network topologies or conditions (Detecting a down link generates a route update)

Finally, OLSR has been modified to support QoS routing based on metrics reported by the MAC. The analysis of the metrics that can be used for routing is an on-going work.

## IV. Demonstration

The objective of the demonstrator is to highlight some of the innovative techniques offered by the WIDENS radio interface and networking protocols. Specifically we will demonstrate:

- Multi-hop relaying
- High bit-rates (> 2 Mbit/s)
- Cluster-Head Synchronization
- Multi-channel operation
- MIMO [4] signal processing

The scenario will consist of prototype nodes equipped with multi-antenna transceivers (see Fig. 4) to demonstrate the benefits of MIMO signal processing in an ad hoc networking environment. Each node is a RT Linux based PC equipped with the Dual Channel PCMCIA card (see Fig. 5). Each one implements the full IP/MAC/PHY stack. Nodes will run Linphone [8] (for audio) and surveillance data applications to demonstrate the performance of the multi-hop wireless communications.

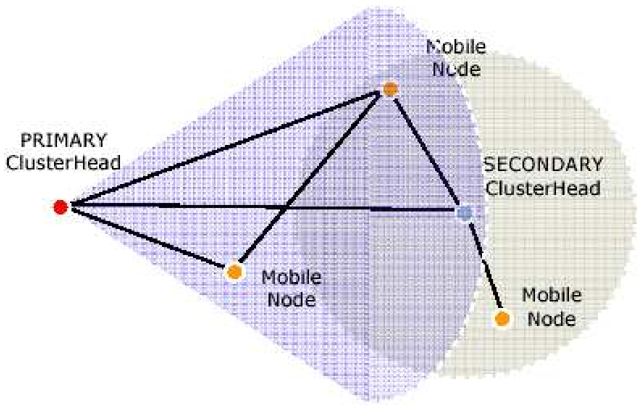


Fig. 4. Demonstration topology.

Subject to authorization from the local frequency regulation authorities, the demonstration will be run over the air. Alternately the full communication chain will be demonstrated, but the generated signals will be transmitted over cables to eliminate illicit radiations while maintaining the same level of solicitation of the equipment.

## V. Conclusion

The demonstration proposed here demonstrates a working prototype of a novel integrated IP/MAC/PHY architecture for broadband wireless ad hoc networks. It shows that the architecture design efficiently supports the basic communications services of voice and surveillance.

## Acknowledgment

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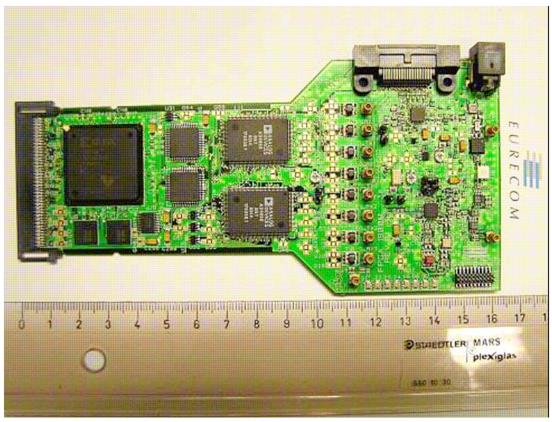


Fig. 5. Dual-channel PCMCIA prototype.