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Research Report RR-05-143
**An Overview of the WIDENS MAC/PHY layer for Rapidly
Deployable Broadband Public Safety Communication
Systems**

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Abstract

This report presents the European Commission Framework 6 IST project entitled Wireless DEployable Network System (WIDENS) that is focused on development of a system concept and technology for rapidly deployable ad hoc broadband public safety networks. The output of the WIDENS project will provide a demonstrator to validate the technology developed in the project and will contribute the development of technical specifications in the context of the transatlantic project MESA. The WIDENS project will contribute to joint EU efforts supporting R&D activities targeting harmonized international standardization of integrated communication system in support of public safety.

The purpose of this Industry/Academia collaborative research effort is to design, prototype and validate a vertically integrated rapidly deployable and scalable communication system for future public safety, emergency and disaster applications. In such scenarios, the communication system must be highly reliable to allow rescue teams to work and collaborate quickly and efficiently. Such operations are strongly dependent on the availability of the communication links both to rescue operators on the fields and to the central control room. However, in disaster areas, the links and central control are subject to failure, leading to a complete collapse of the network. To address these issues, WIDENS exploits the advantages of wireless mobile ad hoc networks in accordance with public safety usage scenarios.

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1 Introduction

The Wireless DEployable Network System (WIDENS) is a publicly-funded collaborative European research project developing radio technology and a system concept for Ad hoc broadband networks for emergency/disaster relief and public safety. The introduction of rapidly deployable inter-operable communication systems for public safety is becoming increasingly important in today's world. The WIDENS network will be an essential part of any disaster relief operation that requires reliable rapid deployment, support of broadband data applications and high capacity. Such systems will prove to be key elements of disaster relief and peace keeping operations. Deployable sensors and sub networks integrated with WIDENS could be efficiently used for instance in the implementation of preventive anti-terrorist measures, environmental monitoring and monitoring of physiological parameters.

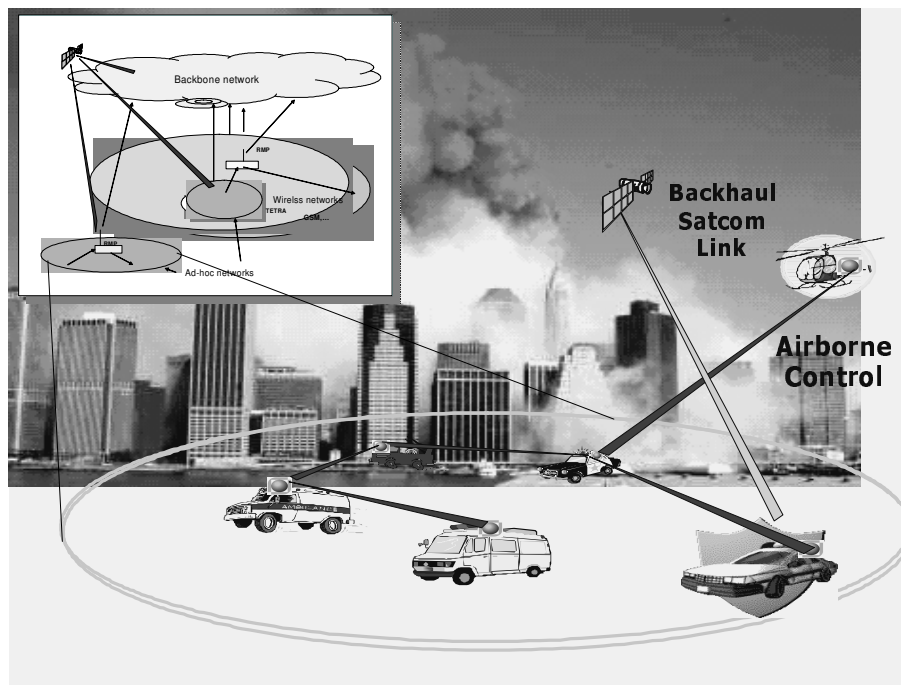


Figure 1: Deployable network component in public safety communication system

WIDENS will be used as a stand-alone system to provide communications for remote hot spot areas while being connected to a backbone network and/or a command and control center via satellite or airborne platform (see Figure 1). It could also be deployed in the areas where communication infrastructure has not been built or was destroyed. WIDENS systems could be deployed as a healing overlay network for the areas where there is a lack of Professional Mobile Radio (PMR)

network capacity (e.g. TETRA www.tetramou.com) in order to support emergency related traffic.

2 Evolution of Wireless Public Safety Networks

2.1 Wireless Professional Mobile Radio (PMR) and Deployable Military Networks

The APCO (www.apcointl.org) Project 25 (www.project25.org) in the US, TETRA and TERAPOL (www.tetrapol.com) in Europe are first generation narrowband PMR digital communication architectures for public safety, internal security, tactical communications and information interchange. PMR systems support a number of teleservices such as point to point call, group call, broadcast call; bearer services such as enciphered digital data, packet switched confirmed/unconfirmed data delivery, circuit switched reliable/unreliable services and supplementary services such as priority call, call interrupt, talking party identification and others. APCO's Project 25 is a digital trunking standard for the US public safety market and is based on FDMA, 12,5 kHz technology. It provides typical cell radius 7.6 km (handheld suburban) 35 km (mobile rural) for interference limited systems. TETRA is an ETSI (www.etsi.org) standard for PMR that is used by a considerable number public safety agencies across the globe. TETRA uses time division multiple access (TDMA), RF carrier spacing 25 KHz, cross channel rate 36.6 kb/s. The typical TETRA cell radius is 3.8- 17.5 km for interference limited systems. Tetrapol is the name for the PMR technology of the French company Matra. Tetrapol technology was selected for French National Police. Also, there are Tetrapol networks installed in Spain, Czech Republic and Switzerland. The Tetrapol technology is similar to APCO P 25 as it uses FDMA with RF carrier spacing 12.5 kHz and GMSK modulation.

2.2 Rapidly Deployable Systems

The development and exploitation of ad hoc wireless communication was considered first for military communications. Existing deployable systems used for military purposes could be used for emergency communications but have never been considered by public safety communities due to high equipment costs and other applicable constraints. DARPA was among the first to initiate a Packet Radio Network (PRN) program in 1972 [14, 10, 9]. Although the initial PRN protocols used a centralized control station, the core PRN concept quickly evolved into a distributed system employing multi-hop store-and-forward techniques. The Tactical Internet (TI) - the US Army's Task Force XXI (TF XXI) program (1997) is probably the largest implementation of a mobile Ad hoc network (MANET) and consist of thousands nodes that include vehicular and backpack radios [18]. It runs modified commercial Internet protocols and uses direct-sequence spread-spectrum, time-division multiple access radio capable of transmitting data at tens

of kilobits per second. In 1994 DARPA initiated the Global Mobile (GloMo) Information research Program which has now concluded [13]. It aimed to provide office-environment, Ethernet-type multimedia (voice, video, images, etc.) connectivity any time anywhere in handheld devices. The future generation of adaptive, multi-band, multimode radios, the Joint Tactical Radio System (JTRC) [4], will offer improved flexibility over half-duplex, single-channel radios at higher layers of the system because of the ability to transmit and receive on different bands and using different waveforms. The next important step in JTRC development will be the integration of broadband transmission capabilities in such systems.

2.3 Standardization Activities

The standardization activities of APCO project 25 are supported by the TIA TR-8 Engineering Committee (www.tiaonline.org/standards/project_25), Mobile and Personal Private Radio Standards. The partnership project between APCO and ETSI for project PSPP (Public Safety Partnership Project) was transformed into the TIA-ETSI transatlantic project MESA in 2001 (www.projectmesa.org). The goal of the MESA project was the development of a specification for broadband ad hoc networks for public safety which is the focus of the technical goal of WIDENS. The scope of the MESA project was expanded in 2004 towards specifying a Heterogeneous - System of System - network concept, where the deployable network component is part of the heterogeneous network for public safety. Besides the MESA and TETRA projects, the European standardization activities of several ETSI bodies such as SC EMTTEL and 3GPP projects have also considered emergency communication functionalities. The evolution and time line of public safety communication systems, related to research and standardization activities is presented in Fig. 2.

3 WIDENS User Studies

The participation of public-safety users plays an important role in the WIDENS project. The dialog with different public safety user organizations provides valuable input to definition of user requirements, reference scenarios, applications and validation of field trials. Discussion and brainstorming sessions have been carried out by user studies with E112 services, firefighters, emergency doctors, peace-keeping forces, search and rescue teams, and private security companies. This work helps to define reference scenarios for each user group and identify the need and relevance of applications requiring broadband communications capabilities and rapidly deployable network functionalities. The user questionnaire is available at the WIDENS website (www.widens.org). The WIDENS user studies help in translating user requirements into technical requirements and develop a set of generalized reference scenario models and network management algorithms that could be applicable for different kinds of emergency scenarios.

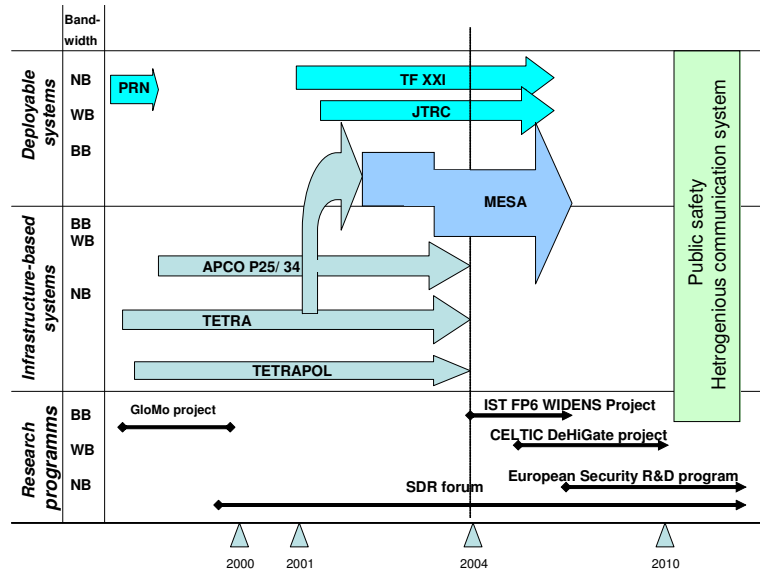


Figure 2: Evolution and time of public safety communications R&D and standardization projects

These studies have shown that the public safety forces, while mobilizing resources for an intervention, are organized in small groups of several units interacting among each other. The detailed organizational structure varies between different public safety organizations, but the main characteristics are the same, the structure is essentially hierarchical: at the bottom of the hierarchy, each rescue unit member has direct connection with his own rescue unit members and with the unit leader. The unit leader is able to communicate with the members in his unit and is responsible for reporting and receiving instructions from the rescue team leader. The rescue team leader is responsible for managing the different rescue unit leaders in the field. Therefore, the design of the WIDENS system takes advantage of the specificity of the organizational and operational constraints of the public safety emergency and disaster relief applications. Furthermore, the clustered and hierarchical nature of communications are taken into account in designing system architecture and in cross-layer optimizations allowing efficient operation of the ad hoc system.

4 WIDENS System Studies

The system studies have the main purpose to demonstrate and validate the WIDENS system parameters and architectures for different public safety user groups. They consider requirements (including operational) of different user groups. The system studies provide information about WIDENS system performance for large

scale WIDENS deployment with set of prioritized broadband services. The system studies are based on results of user studies and translate them into generalized software models available for simulations. The developed models could use deterministic maps of large areas, city districts and buildings or statistical formulas to allow simulation tools to predict system performance. System studies help in obtaining information regarding the feasibility of the WIDENS system concept and technology with different public safety scenarios and to demonstrate the ability of WIDENS network to provide a set of prioritized services required by users. System studies provide information about WIDENS network capacity, coverage, QoS and broadband services availability such as real-time high quality video and large data file exchanges. The WIDENS system studies include network control algorithm optimization such as topology management (clustering), relay node placement optimization and reliability studies.

5 WIDENS System Architecture: Interoperability, Cross-Layering, and Reconfigurability

Fig. 3 shows the architecture of WIDENS aiming to achieve three main objectives of interoperability, cross-layering, and reconfigurability at the same time. First, it conforms with the inter-layer independancy and peer-to-peer principles and hence provides interoperability between different standards at each layer. This provides a modular, upgradeable, and compatible architecture.

Second, it extends cross-layering to all protocol stacks through state information and parameter mapping between adjacent layers. Such a mapping is beyond the regular layered behavior in the sense that if the local adaptation is insufficient to respond efficiently to the local performance degradation, state information and parameters are mapped to the adjacent layer for a more general/specific response. This triggers the adaptation at this adjacent layer. Thus, the mapping might be further cross-layered to the next adjacent layer if the adaptation is insufficient, avoiding loops and unnecessary or unintended cross-layering. Besides, the interactions between non-adjacent layers is controlled via the adjacent layers, allowing cross-layer optimization without affecting the regular functionality of the layer whose response is not sufficient. For example, consider a weak link scenario. The MAC/PHY can respond to weak connectivity by increasing the transmit power or by error correction coding. This will correct the variations in connectivity due to, for example, multipath flat fading. However, if this response is not sufficient, forwarding mechanism at the network layer can reroute traffic through high quality links. If rerouting is not possible, the transport layer can delay packet transmissions until either alternate routes become available or link quality becomes good. Therefore, each layer of the protocol stack responds to local variations and state information from the other layers.

Finally, it rapidly reconfigures the network functions to the system constraints (e.g. radio frequency, bandwidth, authorized transmission power) and network and

application characteristics (e.g. traffic and mobility pattern) at the time of deployment. The advantage of the reconfigurable protocols is that no single system is efficient for all emergency situations due to the huge variability in terrains, traffic scenarios, and mobility patterns. For instance, the design of the air interface uses software-defined radio principles[15] and can be reconfigurable with respect to PHY and MAC parameters (e.g. frame/slot durations, modulation formats, FFT sizes, preamble lengths, etc.) as well as algorithms designed for specific propagation or traffic conditions (multiple-access and channel coding and synchronization strategies, smart antenna processing, scheduling algorithms).

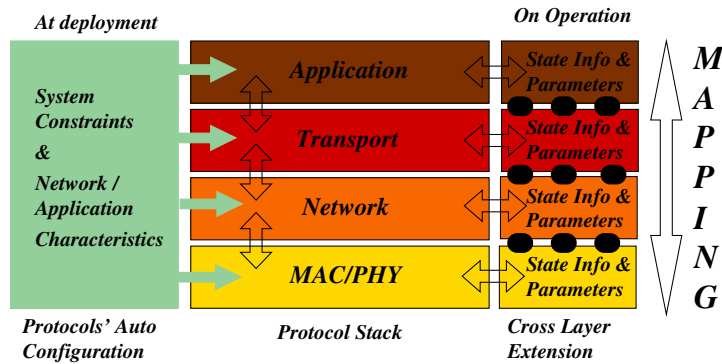


Figure 3: WIDENS architecture aiming at interoperability, cross-layering, and reconfigurability

6 MAC/PHY Co-Design Layer

The importance of the co-design of MAC and PHY layer with cross-layering in mind [6] is taken into account in WIDENS as in some of the latest standardization issues such as IEEE802.11e[8], 3GPP [1], HiperLAN/2 [11]. For example, the data link control (DLC) and PHY layer of Broadband Radio Access Network (BRAN) HiperLAN/2 have been designed for high throughput, low latency, and QoS support. From the point-of-view of the network, the WIDENS MAC looks like an enhanced 802.11e [8] interface, with several QoS streams, corresponding to different traffic classes. The primary difference in the air-interface with respect to 802.11e, is that the physical layer is not seen as single-pipe from the MAC, but rather a set of physical resources (frequency groups, antennas) over which to schedule packets, and thus time is not the only resource which the MAC can control. Moreover, special signaling channels have been introduced to provide higher spectral efficiency and hard-QoS support. The WIDENS PHY provides high bit rate wireless links using OFDM modulation with high-order QAM constellations. The use of OFDM modulation makes transmission very robust to the dispersive channel resulting from frequency selective fading. In addition, support for multiple-antennas in the transmitter and receiver [7], allowing for MIMO (multiple-input multiple-output) techniques to be employed (space-time coding, spatial-division

multiple-access, etc.).

The WIDENS MAC is time-slotted and synchronized by special nodes, called clusterheads, which play the role of the hybrid coordinator in 802.11e networks. This is motivated by the clustered nature of the application as determined by the user studies(see section 3). Nodes associate themselves with the clusterhead (as in 802.11e) after synchronization and can be associated with more than one, which allows for interconnection of clusters via these so-called relay nodes. An example is shown in Fig.4. The role of cluster head is to regulate traffic within the cluster by scheduling transmission opportunities based on traffic volume measurements signaled by terminals and network layer QoS reservations. Transmission opportunities are interference-free with respect to terminals within the cluster. It should be noted that the clusterhead is not necessarily an access-point and that there is no concept of uplink and downlink as in cellular or wireless local area networks, so that traffic routing is determined by the network layer and not by the MAC-layer topology. Each node can route information and is thus equivalent from the point-of-view of the network layer. During transmission opportunities, terminals can schedule their traffic queues over physical layer resources using reconfigurable scheduling policies satisfying different QoS scenarios and based on wideband channel measurements with respect to their destinations (for example channel driven wideband opportunistic or constant-rate scheduling [20][19]).

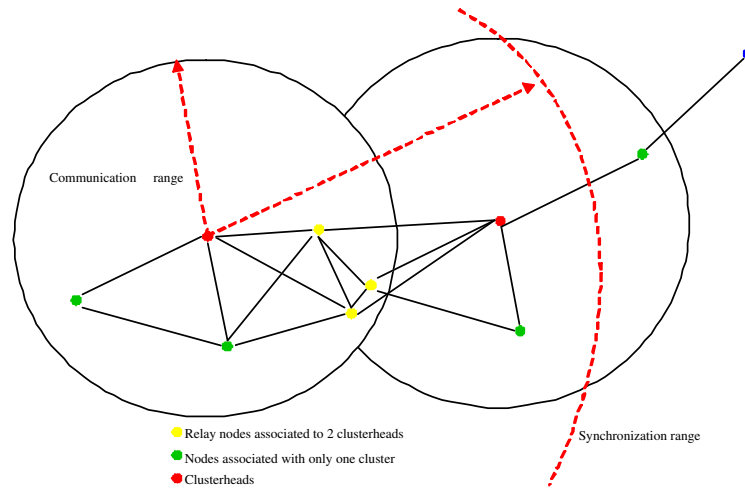


Figure 4: WIDENS cluster and terminal association to the clusterhead

In addition to synchronizing nodes within communication range, the cluster-head synchronization signal is designed to allow for adjacent clusters which are out of communication range to synchronize to each other (potentially in a distributed manner) by ensuring time/frequency tracking over longer distances than those considered in the link level analysis (i.e. for transmitting data).

6.1 Channelization

Fig. 5 shows the general DLC/MAC/PHY architecture. The management and data services of the DLC service are operated by the MAC layer that maps the DLC packet data unit (PDU) on the MAC frame components, namely clusterhead broadcast channel (CHBCH), measurement channel (MCH), random access channel (RACH), scheduled access control channel (SACCH), and scheduled access channel (SACH). The DLC messages are delivered on three logical channels as the following:

- The Cluster Control Channel (CCCH) logical channel provides to the MAC of the cluster head the set of information that is required to operate on SACH (i.e. contention free period).
- The Management and Control Channel (MCCH) logical channel provides to the MAC all DLC management PDU (MPDU) that are required to operate the management services. The management services of the DLC sub-layer consists of several components including the QoS management, the cluster management, the radio resource control, and the address resolution.
- The QoS Traffic Channel (QTCH) corresponds to the set of destination-QoS queues that contain the data PDU to be mapped by the second level opportunistic scheduling (see section 6.3).

The DLC logical resources are then mapped into MAC/PHY resources, namely CHBCH, MCH, RACH, and SACCH/SACH. A part from the aforementioned channels, the physical layer owns an extra channel called clusterhead synchronized channel (CHSCH).

- The clusterhead synchronization channel (CHSCH) is a signaling resource reserved to a WIDENS clusterhead which is responsible for delivering synchronization information to terminal in the cluster. This channel is used by terminals to acquire timing information regarding the beginning of MAC frames and to perform initial frequency offset adjustments with respect to the carrier frequency of the clusterhead. The channel is also used by adjacent clusterheads to synchronize the network, in order to facilitate inter-cluster communication under quality-of-service guarantees. It is emitted once per frame in conjunction with the clusterhead broadcast channel (CHBCH). Aside from its primary purposes above, it is also intended to be exploited for channel estimation prior to demodulation of the CHBCH, since the CHBCH does not comprise pilot signals and the clusterhead does not use the MCH. The CHSCH is a spread-spectrum signal detectable for much lower signal-to-noise ratios than the data. It is thus detectable beyond the communication range of a cluster, and therefore by adjacent clusterheads.
- The clusterhead broadcast channel (CHBCH) is the signaling channel used by the DLC (mainly CCCH channel) for passing basic protocol information

from the clusterhead to the terminals in its cluster. This information is used to distribute physical resources during the frame and some additional protocol information (association, QoS reservation, etc.). It is located in the first available slot in the frame. In the case of several clusterheads operating on the same carrier frequency, the CHBCH of adjacent clusters (i.e. those within range of the CHSCH) cannot collide and thus must be allocated different slots in the frame. The same is true for the CHBCH and MCH/RACH of adjacent clusters. The allocation of CHBCH/MCH/RACH across several clusters must be accomplished in a distributed fashion based on the activation times of the different clusterheads and mobility of the clusters.

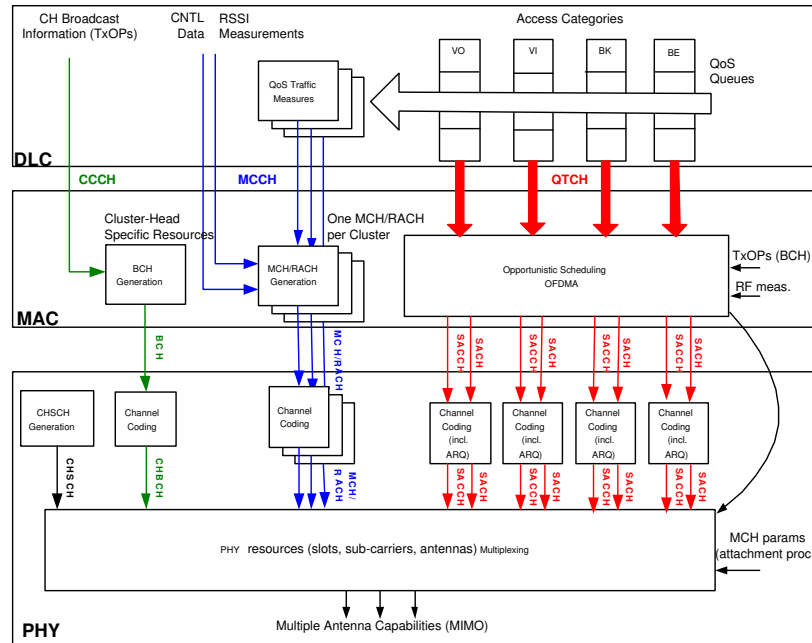


Figure 5: MAC/PHY architecture

- Measurement channel (MCH) is a broadcast signaling channel used by terminals (with exception of clusterheads) to provide protocol information for QoS scheduling to the clusterhead as well as link quality indicators to surrounding terminals (DLC MCCH channel). In addition, it contains pilot symbols for wideband channel estimation to be used by surrounding terminals when allocating SACH resources. The transmit power of the MCH is conveyed by higher layer signaling so that open-loop power control can be performed. An MCH is a mini-slot of at least 1 OFDM symbol and terminals have a single MCH resource per cluster and per frame. Since this is a broadcast resource destined to all surrounding terminals in range it shall use the lowest spectral efficiency (highest sensitivity) coded-modulation format.
- Random access channel (RACH) is a signaling channel used primarily dur-

ing the association phase of a terminal and for other management services (i.e. DLC MCCH channel). The RACH uses the same signaling format as the MCH, although typically less total resources. Several RACHs can be used in parallel to reduce contention in dense networks. This resource is not meant, however, to be used for intensive data transmission. Data streams consisting of small sporadic packets could potentially use this channel if required. The primary difference between the RACH and the MCH is that the transmit power is subject to power control. This is because the destination of the RACH is always the clusterhead and the transmit power should be adjusted in a closed-loop fashion based on the measured path loss between the terminal and the clusterhead.

- Scheduled access (SACH) and scheduled access control channel (SACCH) are multiplexed resources containing both signaling information and user plane traffic (DLC QTCH and possibly MCCH). The SACH is a set of data streams multiplexed by multiple-antenna OFDMA containing user traffic for several destinations. The SACCH contains low-layer protocol information regarding sequencing (for ARQ and channel decoding) and signaling for channel feedback mechanisms. The SACCH is a resource common to all destinations sharing the SACH and its data is multiplexed with those of the SACH. Aside from low-level signaling it contains the allocation formats used by the set of streams in the SACH, specifically the frequency allocations and coded-modulation formats.

6.2 Frame Structure and Channel Access

The time-frequency plane is organized in frames and time-division duplexing (TDD) is used on each frequency channel. Each frame is partitioned in slots, and divided into several channels, namely CHSCH, CHBCH, MCH, RACH, SACCH/SACH. Parameters such as the frame length, slot duration, channel bandwidth, are reconfigurable at deployment, in order to adapt to regional spectral requirements. We note again that there is no concept of uplink/downlink as would be the case in 802.11e, Hiperlan2, 802.16 or 802.15.3 networks.

6.2.1 Random Access

This access scheme is only used in RACH channel, and it consists of transmitting packets randomly, like in slotted Aloha, which can collide in time. The erasures are then corrected by the forward error correction (FEC). Note that this is comparable with distributed coordination function (DCF) in IEEE802.11 legacy, and it is a contention period (CP).

6.2.2 Scheduled Access

The Scheduled access scheme is used in MCH and SACCH/SACH, which consists of allocating some slots for particular users (or potentially groups of users) on a frame-by-frame basis. Indeed, the SACCH/SACH slots are granted based on measurements transmitted from nodes to the CH through the MCH. These slots should be seen as transmission opportunities for terminals to access the channel in a contention free manner, at least with respect to users in the same cluster. The scheduling information is embedded into the CHBCH channel, and indicates how the slots have been allocated to the users. So, certain users are allowed to transmit all or part of their data during the scheduled access.

Note that this is comparable with polling coordination function (PCF) in IEEE 802.11 legacy, and it is contention-free period (CFP). The main difference is that the users can use the transmission opportunities as they wish, potentially with advanced multiuser scheduling techniques if they serve several destinations. Moreover, this is not necessarily a link with the clusterhead, but can be used to communicate with any other terminals in the same or different cluster. Within transmission slots, terminals may multiplex streams to different with OFDM symbols (i.e. OFDMA).

6.3 Advanced Hierarchical Opportunistic Scheduling

Scheduling algorithms are important components in the provision of guaranteed quality of service parameters such as delay, throughput, and etc. The design of scheduling algorithm is challenging task given the high variation of link error rates and capacities, and the frequent topology changes typically encountered in WIDENS network. MIMO and dynamic channel allocation techniques are the targets of the WIDENS system. Indeed, a system that combines these two techniques can provide data transmission with very high spectral efficiency, and thereby meet the high speed requirements of WIDENS.

WIDENS terminals surely will have to work in time varying fading channel environments. In such environments, opportunistic or multi-user diversity scheduling might help to manage time resources in a more efficient way [12][20][19]. Opportunistic or multi-user diversity scheduling schemes are based on the idea that access to the channel should be given to the terminal with better channel state. Hence, before transmitting user data, the channel state is estimated and, according to such instantaneous channel state information, the best terminal's data are scheduled. Initially, scheduling the best terminal is equivalent to scheduling the terminal with best channel state defined by the signal to noise ratio (SNR). However, best terminal's goodput scheduler criterion will be also considered in WIDENS terminals.

Two strategies can be adopted for channel strength measurements. First, through unicast feedback channels, which are required in interference-limited situations and if accurate amplitude and phase information is needed. The second type of strategy exploits channel reciprocity. The latter does not require a feedback

channel but, in contrast to cellular networks, does require a resource for Terminodes to broadcast pilots so that other nodes can measure the common channel between them before its own transmission (in cellular networks the basestation always broadcast anyhow and terminals only have the basestation as their destination, thus broadcast pilots are not required). The feedback can therefore be either broadcast (for all Terminodes) or unicast (specific pair of Terminodes) and may or may not contain signaling data (i.e. channel measurements, buffer occupancy, delay measurements, etc.), but only pilot information.

The scheduling in Widens exploits the multiuser diversity through the broadcast feedback channel (and possibly through the channel reciprocity), and is performed at two levels: Clusterhead, Terminode. The scheduling of total scheduled resources is performed by the clusterhead in the RRC function. This scheduling is based on measurements obtained from the terminodes (through the MCH channel) regarding their backlog in QoS queues. Within the allocated SACH resources (also referred as transmission opportunities TxOps), the terminode shall attribute resources according to an opportunistic scheduling algorithm which maps data from its QoS traffic queues to the OFDMA physical resources. The algorithm can be opportunistic in the sense that it can benefit from the time/frequency varying nature of the mobile radio channel. The scheduling algorithm can choose how many streams to service and what physical resources to attribute for each stream (coded-modulation format, number of frequency carrier groups, etc.)

7 WIDENS Prototype

A complete demonstration platform is currently under development targeting a field trial in Sophia Antipolis, France in February 2006. The WIDENS demonstration equipment will be based on existing software-defined radio (SDR) technology from Eurecom. This equipment was already used to demonstrate innovative networking and radio-interface aspects in several publicly-funded research projects and software is being developed to suit the needs of WIDENS. The existing equipment operates using standard PCs and custom-made RF equipment. New reduced form-factor PCMCIA SDR modules were developed in the context of WIDENS. These are shown in Fig. 6 and are both MIMO capable (two-antennas) and multi-frequency capable (2GHz and 4-6 GHz). The WIDENS radio equipment should be tunable over a wide bandwidth in order to accommodate regional differences in spectral allocation. The initial prototype will target 5 MHz channels from 4000-5500 GHz (in addition to 1900-1920 MHz operation), which includes the spectrum liberated for broadband public safety systems in the North America (4940-4950 MHz). This spectral agility is coherent with the reconfigurability feature of the system architecture. Transceivers are MIMO (multiple-input multiple-output) capable and will support transmit powers of up to 27 dBm (5 MHz channels) per antenna element.

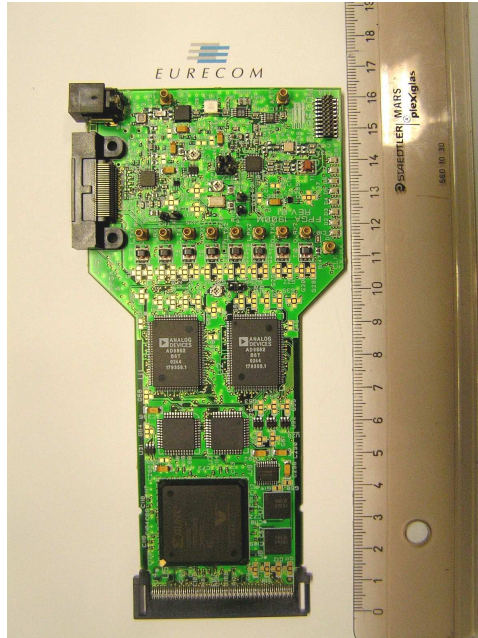


Figure 6: Dual-Channel SDR PCMCIA Prototype

7.1 Demonstrator System at Sophia Antipolis

The demonstration network for the WIDENS field trial will comprise 6 terminals organized into two clusters. The field-trial area will be around Institut Eurècoms premises in Sophia Antipolis, which can be characterized as a hilly and lightly-forested terrain. The demonstration network will consist of two clusters with one node in mobility to demonstrate seamless connectivity. The goal of the demonstration 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)
- Clusterhead Synchronization
- Multi-channel operation
- Interconnection with the Internet, cellular networks and other PMR systems
- Limited mobility support
- MIMO signal processing

8 Conclusion

The WIDENS project aims at designing, prototyping, and validating a rapidly deployable and scalable communication system through a wireless mobile ad hoc network for future public safety, emergency, and disaster applications. The WIDENS architecture extends the standard layered-independancy to support cross-layering on operation, and reconfigurability at the deployment. The project has produced the system specifications for a wireless mobile ad hoc communication system for public safety applications. These specifications were presented above and rely on a cross-layer optimization principle. The next step in the project is to validate the design. Simulations and models of various communication patterns will be carried out. A prototype will be implemented using Eurecom's existing Software Radio Platform. A reference implementation and simulation environment will be available for download under the GNU general public license and released in the public domain. A full RF demonstrator will be set up in the course of year 2005 and field trials will begin in 2006.

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A Network Layer Design

This section presents how classical network layer design has been refined to efficiently respond to public safety needs and improved by MAC-awareness information and advanced QoS mechanisms. In this context, WIDENS proposes a novel

vertically integrated solution to hard-QoS guarantees, reliable wireless secured infrastructure and to ad hoc network deployment control for public safety networks (or applications).

A.1 Modular and Extensible Network Layer Design

The WIDENS network layer can be logically decomposed in four set of components, which interact among each other to ensure hard QoS capabilities, to provide efficient dynamic network control, to preserve robustness of the network through optimized co-operations with the WIDENS MAC/PHY layers. As shown by Fig. 7, these sets of components are:

- The Advanced QoS Components, which allow a node to make local decisions for delivering IP packets through QoS routing and reservation. They are in charge of the QoS and routing signaling required for managing the dynamics of routes and associated QoS parameters.
- The Management Components, which provide node location information to configuration and monitoring applications.
- The Efficient Security Components, which ensures robustness to the deployed network thanks to nodes authentication.
- The Cross-Layer Interface, which enables fast reactivity and optimizations of the network layer components to efficiently respond to wireless channel variability and high topology dynamics, thanks to direct access to MAC/PHY layers information and events.

The following sections detail the main properties and characteristics provided by the WIDENS IP/MAC cross-layer approach.

A.2 Increased Routing Flexibility and Optimizations

Analysis of mobility patterns, nodes density and traffic loads leaded WIDENS to use the Optimized Link State Routing protocol (OLSR) as the basic routing component for its prototype. OLSR is a proactive routing protocol [3] that works as classical link state protocol by advertising information on existing links to the network after which an algorithm similar to Dijkstra's algorithm is used to compute shortest-path routes to all reachable nodes in the network. The dissemination of topology information is done by using so called Topology Control (TC) packets which are used by a node to advertise the links to its neighbors. The TC packets are sent out periodically. The OLSR protocol prescribes a HELLO message exchange to perform link sensing.

The proactive nature of OLSR responds to instantaneous routes availability required for Public Safety crucial communications. OLSR reduces also the network overhead, induced by the proactive signaling, by the selection of specific nodes: the

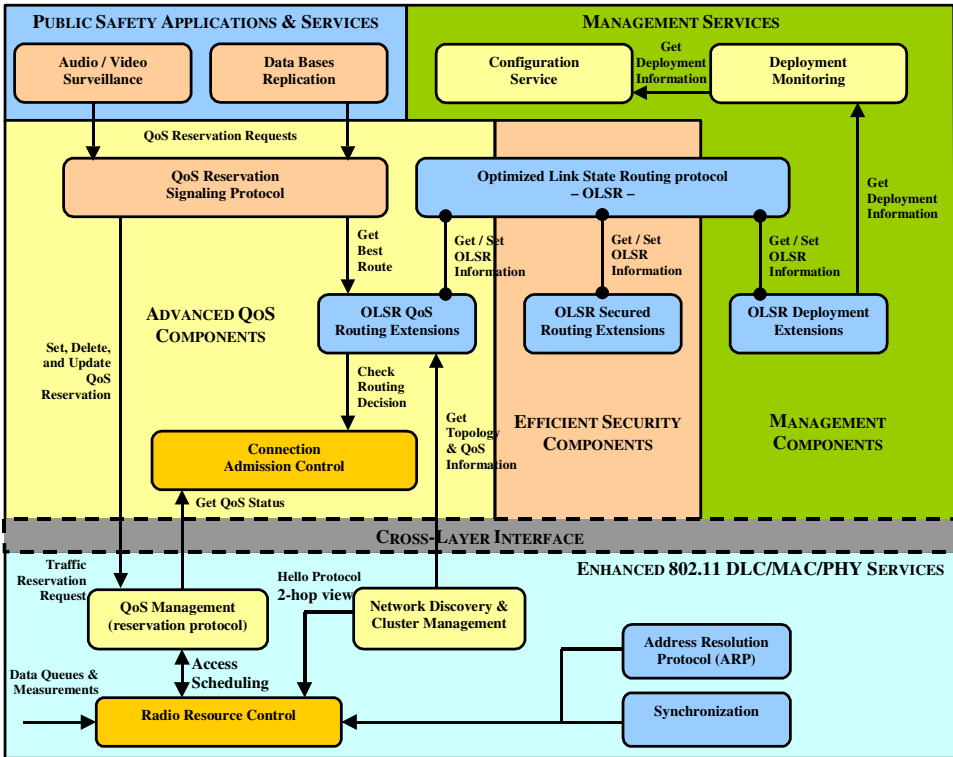


Figure 7: WIDENS Mac-Aware Network Layer

Multi-Point Relays (MPRs). Only these nodes are responsible of the TC messages transmission and forwarding in the entire network.

Therefore, taking advantages of the interesting OLSR properties and to respond to current and to future requirements of Public Safety communication infrastructure deployment, the routing sub-system has been designed extensible and modular. In fact, new dedicated protocol extensions, respecting full compatibility with the standard OLSR, can be designed in order to reinforce the routing functionality for the context of Public Safety. Currently, the project specified the following extensions:

- The OLSR QoS Routing Extensions, which exchanges nodes QoS resources availability provided by the MAC layer through the Cross-Layer Interface (e.g. available bandwidth). This feature provides to the WIDENS network layer the ability to accurately manage applications flows thanks to the knowledge of the computed network load state and, in this way, to respond to applications QoS needs and privatization.
- The OLSR Deployment Extensions, which transmit location information of nodes to benefit and to facilitate Public Safety units monitoring.
- The OLSR Secured Routing Extensions, which ensure the reliability and the robustness of the routing infrastructure (i.e. the routing information, nodes and processes) thanks to efficient authentication procedures in accordance with Public Safety requirements.

Additionally, to the design of these extensions, the OLSR protocol has been also optimized in such a way that link sensing is no more performed at the network layer. In fact, finding or losing a link to a neighbor using a network layer mechanism implies always a significant delay. The WIDENS optimized OLSR no longer uses HELLO packets but gather neighborhood information directly from the MAC layer using the Cross-Layer Interface. In this way, the WIDENS version of OLSR reacts better and faster to network dynamic.

A.3 Ensured Hard-QoS Guarantees by IP/MAC Cross-Layer Design

Close interactions between IP and MAC layers, which conform to inter-layer independancy and to peer-to-peer principles, joint to efficient Connection Admission Control (CAC) mechanisms allowing not only to increase WIDENS performances but also their efficiency by providing a more accurate control of network QoS resources (e.g. bandwidth or delay). An RSVP-like reservation scheme is used to provide global hard-QoS guarantees by allocating resources along routes. The decisions to admit new connections according to their required QoS guarantees and the available resources are taken by the CAC module. The WIDENS network layer has been designed not only to perform routing in the most efficient way regarding network resource consumption, but also to provide short response time to applications.

In order to establish the route for a new connection requiring QoS guarantees, the IP layer needs to find out a possible route that is able to accommodate the resources needed by the new connection. To do so, the following cases can occur:

- The source and the destination are in the same cluster.
- The source and the destination are in different clusters. In this case, the route can be segmented into the different Route Sections (RSs) where resources have to be allocated. These RSs can be: intra-cluster, and backbone RSs. Since each RS uses independent resources, independent CAC must be applied to each RS.

The CAC algorithm targeted to support the reservation scheme works as follow. Given the Maximum Available Bandwidth (MAB_i) for QoS traffic at each Mobile Node i (MN_i) the following conditions have to be satisfied: *QoSconstraint* : $MAB_i \leq 0; \forall i$. The MAB_i values are dimensionless and can be interpreted as the percentage of free slots available at each MN_i . $MAB_i = 0$ means that no capacity is left for QoS connections at MN_i . $MAB_i < 0$ would mean that the capacity that MAB_i is sharing has been over-reserved.

A.4 Ensured Robustness by Secured Routing Capabilities

Security is another key-challenge addressed by WIDENS, functions such as member or group authentication, access control, confidentiality and data integrity are strong requirements in Public Safety.

The security scheme retained in WIDENS includes features that take place at two layers:

- Network layer: As an extension of OLSR in order to provide reliability to the network by preventing malicious nodes to inject corrupted control traffic. It uses asymmetric signatures for authentication between nodes and time stamps to counter replay attacks. In the standard OLSR version nodes can come with completely wrong routing information because it can receive fake HELLO or TC (Traffic Control) messages from an intruder in its neighborhood. A distributed Private Key Infrastructure (PKI) is used for key management.
- Application layer: Since providing security for end-to-end data communication is equivalent to that in wired networks, WIDENS takes the benefit of the PKI to ensure security between peers.

The solution proposed in [2] to provide authentication in Ad hoc networks is the basis of the WIDENS mechanism at the routing layer. WIDENS use the OLSR header defined in [2] to support securing of the routing protocol. Nevertheless, some improvements have been proposed: the implementation of a message signature with X.509v4 certificates, the usage of a certificate cache in order to minimize certificate requests and the utilization of both RSA and ECC keys.