Overview of the WIDENS Architecture, a Wireless Ad Hoc Network for Public Safety

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***Abstract*— This paper highlights preliminary results and status for the European Project entitled *WIreless DEployable Network System* (WIDENS) [1]. The purpose of this Industry/Academia collaborative resiearch 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. The project partners[1] are designing the system and software architectures, and prototyping the radio frequency, air interface, network, and application level hardware and software. The project supports the on-going European involvement in the joint ETSI/TIA standardization initiative MESA (Mobile Broadband for Emergency and Safety Applications). The design and prototype developments will contribute to the development of future broadband private mobile communication systems.**

I. Introduction to the WIDENS Network

The goals of WIDENS project are the following: (i) in terms of technology: to invent and demonstrate solutions that make rapidly deployable and scalable communication system for future public safety effective, and (ii) in terms of market: to propose ad hoc hotspots as access networks to existing Private Mobile Radio systems such as TETRA and TERTRAPOL (iii) in terms of standardization activities: to support european participation to the on-going activities of the MESA group.

Potential users for the WIDENS communication system are the public safety professionals from different organizations: fire services, police, emergency medical services, and other participating authorities, e.g. environmental or military experts. The public safety forces, when they mobilize 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 of managing the different rescue unit leaders in the field. The purpose of the system is to offer a common communication channel through a wireless ad hoc network to all actors in an emergency situation in the field of operation at the time of intervention, for each organization and across organizations.

[1]See www.widens.org

In emergency situations, the public safety forces may face different scenarios. These scenarios, depending on the type and size of the disaster, can be classified in four major groups from the topological point of view: (i) *Concentration:* Emergency services concentrated in a point (e.g. a bus crash); (ii) *Front:* Emergency services working along a front line (e.g. fire in a forest, floods); (iii) *Ring:* Emergency services working around (but not inside) a place (e.g. urban fires, bank robberies, bomb deactivation); (iv) *Random Distribution:* Sparse/very wide disasters in a wide area (e.g. an earthquake, a terroristic attack).

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. The clustered and hierarchical nature of communications are taken into account in designing the architecture and cross-layer optimizations allowing efficient operation of the ad hoc system.

The rest of the proposal is organized as follows. Section II highlights the architecture principle for the cross-layer optimization of the system. Section III summarizes the MAC/PHY layer design. Section IV presents the network layer design. Finally section V draws concluding remarks and highlights some future work.

II. Architecture: Interoperability, Cross-Layering, and Reconfigurability

Fig. 1 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.

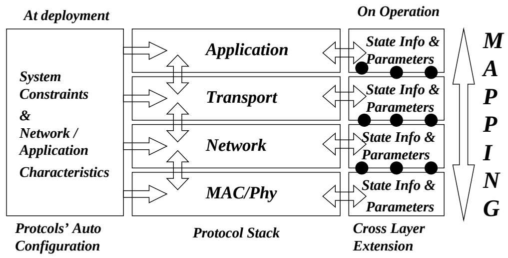

Fig. 1. WIDENS architecture aiming at interoperability, cross-layering, and reconfigurability

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 [2]. 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 in 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. To sum up, each layer of the protocol stack responds to local variations and state information from the other layers [3].

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 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).

We are aware of one existing architecture named MobileMan that deals with the cross-layer design through data sharing [4]. Similar to MobileMan reference architecture, the WIDENS architecture satisfies the layer-separation principle. In contrast, WIDENS does cross-layering via mapping only between adjacent layers, while MobileMan does through so-called *network status* that functions as a repository for data sharing among all layers. WIDENS also introduces reconfigurable design parameters chosen at the time of deployment to adjust the functionality of the protocol stack to different system constraints and environments.

III. MAC/PHY LAYER DESIGN

A. Radio Frequency Equipment

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, 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 will be MIMO (multiple-input multiple-output) capable [5] and will support transmit powers of up to 27 dBm (5 MHz channels) per antenna element.

B. MAC/PHY Co-Design Architecture

The importance of the co-design of MAC and PHY layer with cross-layering in mind is taken into account in WIDENS as in some of the latest standardization issues such as IEEE802.11e, 3GPP, HiperLAN/2. 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 [6].

The WIDENS network aims at providing high bit rate wireless links using OFDM(A) modulation (802.16x proposals [7], 3GPP HSDPA [8]) with high-order QAM constellations. The timing and frequency synchronization will be achieved with specially designed synchronization sequences periodically broadcasted by the best located Terminodes within the cluster that acts as *coordinators*, which permit accurate simultaneous time offset estimation and carrier frequency tracking. Terminodes will lock in time and frequency on a frame-by-frame basis to these synchronization signals (see Fig. 2). 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.

The channel access is hybrid in the sense that it operates both on random and scheduled access. The limit between random and scheduled access is dynamically adjusted by the coordinator to maximize resource utilization with respect to the overall traffic characteristics within a cluster. Scheduled access can be seen as transmission opportunities for Terminodes given by the coordinator in the broadcast channel (BCH). Traffic does not necessarily pass through the coordinator since routing is determined by the Network Layer. Terminodes are at liberty to schedule their traffic accordingly with their transmission opportunities or potentially in the random-access phase.

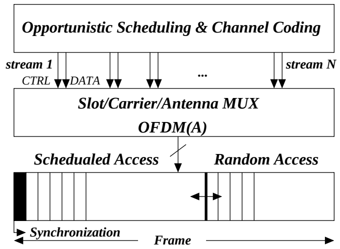

Fig. 2. MAC/PHY architecture

The MAC/PHY layer combines opportunistic scheduling techniques [9] and channel coding/ARQ in a single entity (see Fig. 2). The data units are scheduled across contention and contention-free period according to QoS levels and physical resources (i.e. frequencies, antenna, time slots). This indicates that the resource allocation is done at the MAC allowing for rapid response time. The MAC/PHY layer is multiuser/stream capable (in contrast to IEEE802.11 legacy) due to time-frequency slotted nature of the channel and the OFDM(A) characteristics.

IV. Network Layer Design

The Network Layer functionalities identified for WIDENS are gathered into three different planes, which correspond to three different time scales : the forwarding, control and management planes. Forming an ad-hoc network, the WIDENS Terminodes act both as routers and as end-devices and take advantage of the cross-layering design to optimize communication channel usage. The forwarding plane is implemented in kernel space, while control and management planes are implemented as processes in user space [10].

A. Forwarding plane

The forwarding plane implements time critical functions and increases its efficiency by mapping properties between Network Layer and MAC/PHY Layer. This plane consists of the following functionalities : forwarding determines the next hop to which a packet must be relayed; access control, associated with security, checks if the packet can be accepted or not by the system; packet classification filters packets in order to perform differentiated QoS; policing checks that the current flow traffic characteristics are in accordance with the declared traffic descriptors; to respond to QoS requirements, scheduling can be performed at the Network Layer or directly at the MAC/PHY Layer due to cross-layering design.

B. Control plane

The management plane covers the network deployment phase by translating users requirements into network configurations. It represents the necessary elements to make the link between users and the WIDENS system. In fact, due to the management functions, a Terminode is not only a network element but becomes an active element of the global WIDENS system in a specific operating context. It is in charge of the setting of the communication patterns, application profiles and organization policies specific to the emergency operation, the management of keys to be used by security functions, the addressing configuration and the log storage.

C. Management plane

The main task of the control plane is to establish and to control communications between MAC/PHY clusters, since intra-cluster communications are essentially managed by the MAC/PHY coordinator. It interacts with applications and with the management plane and modifies dynamically the tables and parameters used by the forwarding plane. Control functions involve coordination between the nodes of the network, organized in clusters by the MAC/PHY Layer. It uses signaling for information exchange. Routing is the function that allows each node to be able to determine the next hop node to which a packet must be relayed to reach a given destination. To guarantee availability of network resources for a specific flow, reservation is performed through signaling and admission control. Security functions provide integrity and authentication of the terminodes implied on the routing protocol, to prevent basic attacks on the routing protocol like black hole attack or a routing table overflow.

V. 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 an extension to Eurecom's Software Radio Platform,[2] and the code will be developed 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.

Acknowledgment

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