Wireless Data Communications Using DECT Air Interface

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DECT is an approved ETSI standard for cordless communications, defined as a general radio access technology that can be used as the air interface to any network. In addition to the well-established voice service, it supports data communications. DECT currently addresses low bit rates, but additional modulation options have recently been included for high-speed, up to 2Mbps. In this paper, we describe the hardware and software design of an entire wireless communications system to be used in SOHO applications. While putting the emphasis on data communication, we demonstrate the feasibility of maintaining the compatibility with existent voice terminals. We developed generic hardware and software components, which revealed a very flexible approach. We easily created a wireless LANs, extended an Ethernet LAN and provided access to ISDN[1].

1. INTRODUCTION

The extraordinary commercial success of cellular phones and laptop personal computers demonstrate the enormous interest of users for mobile and wireless communications. Increasing demands for high-speed data transfers, video and multimedia also exist. Thus, high bit rate wireless communications technologies are currently being developed and standardized. ETSI, in Europe, and IEEE, in USA, are maintaining standardization activities for wireless LANs. Moreover, ATM Forum formed a Wireless ATM Working group to develop specifications for wireless access to ATM networks. WATM can be used for Wireless LANs.

In the home, the growing number of PCs, peripheral, intelligent devices and network possibilities face users with new opportunities. These opportunities require a common connection between the various devices and networks found in the home. However, in order to be effective, the connection must avoid home wiring. Without standards specifications, the benefits of wireless networking might never reach its true potential. In addition, the use of standards will facilitate economy of scale, drastically reducing hardware and software prices. DECT, from ETSI, is an approved standard for cordless communications suited for SOHO applications. More recently, the HomeRF group, formed by computer and telecom companies, and Bluetooth, another industry alliance, focused in providing solutions for the SOHO environment.

DECT [1] supports voice and data communications, and addresses a large range of applications, such as telephones WLL, PABX, etc. In the first years of its existence, DECT was mainly used in residential cordless voice applications and today many products exist on the market. During the last two years, other areas as PABX systems and WLL lines have developed

[1] An interface for PSTN line with a V.90 modem is also prototyped

successfully[2]. DECT has also been proposed to the ITU, as family member of the International Mobile Communications (IMT) 2000 system and it has been acknowledged that DECT fulfils the IMT 2000 requirements.

The HomeRF SWAP [2] system is designed to carry both voice and data traffic and to operate with PSTN. It was derived from extensions of DECT and 802.11 wireless LAN standard. The version 1.0 of SWAP specification is already available. The protocol architectures closely resembles to the IEEE 802.11 standard in Physical Layer and extends MAC layer with the addition of a subset of DECT standard to provide isochronous services as voice. SWAP operates in 2.4GHz ISM band providing 1 till 2 Mbps data transfers. Bluetooth [3], operating in the 2.4GHz ISM band, is a technology specification aiming to serve as interconnection for devices in the short range (up to 10m). The gross data rate is 1Mbps. Its primary focus is in the wireless connections between mobile computers and/or between computers and cellular phones, but it supports data rate up to 721kbps as well as three voice channels. Demo cards (Digianswer Bluetooth Demo Card V1.0) are already announced for Bluetooth members for the first half of 1999.

Although DECT addresses data, data communications are not yet well explored due to the fact of people are looking for high-speed data communications. We believed in DECT as a good technology for data communications in SOHO applications. Connections to ISDN, PSTN and ADSL (256 kbps) are now feasible. Even when ADSL will attain higher bit rates in residential applications, new modulation schemes will keep DECT on the market. Since 1996, we are using DECT capabilities for data communications. We did an experiment, using DECT to implement a wireless extension to the Ethernet LAN. However, at the time, we were employing a DECT chipset for voice that did not support protected B-field. Therefore, we implemented error protection with higher level software. After having changed to the current chipset and implementing protected B-field, things became easy. With the new chipset we wrote code at MAC layer to control data connections. We evolved to a generic solution, keeping in mind LANs, but orienting the development for SOHO environments. We implemented hardware and software components for an entire wireless communications system. While putting the emphasis on data communication, we demonstrate the feasibility of maintaining the compatibility with existent voice terminals. We developed generic hardware and software components, which revealed a very flexible approach. We easily created demonstrations of a wireless LAN, of an extension to the Ethernet LAN and an access to the ISDN basic access. Recent development to access PSTN lines, based on V.90 technology, demonstrated again the flexibility of existent components.

DECT is already a reality for SOHO applications [4] [5]. Based on DECT and for ISDN access, these systems use the EURO-ISDN protocol, provide voice and data communications and support type A and B services and Class 2. The first one uses an Intermediate System Configuration [6], providing a wireless extension to the ISDN S0 bus. The other, using the End System Configuration has followed a different approach [7] like we do in our system for ISDN lines. In the End System Configuration, DECT terminals may be considered as the end-point of the ISDN communication path. The base station is connected to the ISDN S0 bus. We can also

[2] Use of DECT in WLL lines is competing with success against PHS, GSM and CDMA technologies

refer the Harris Prism system as a possible solution for data in the SOHO environment. It implements the 802.11 standard at 1 and 2 Mbps. Connecting a modem to a PC, external connections can b e established. Wireless systems can be developed with Harris Prism PC-Cards.

In summary, our approach for wireless data communications has many benefits, including:

- Use of an evolutionary and low cost mass-market technology:

DECT is well established for voice communication in residential, PABX and WLL applications, and is evolving to support high-speed data communications. It uses GFSK, which is a two level modulation schema, supporting from 32 till 880 kbps raw bit rate. In order to support higher bit rates, in a fully backward compatible way, $\pi/4$ DQPSK (64 till 1760 kbps) and $\pi/8$ DQPSK (96 till 2640 kbps) modulation schemas has been added to standard.

- Use of generic modules for rapid configuration and rapid incorporation of advances:

Two generic hardware modules were developed: a PC-card and an ISA board. A base station for public network access (ISDN) was also built. PC-Cards and ISA boards can be configured, by software, as terminals or base stations. Moreover, terminals, running the same driver, can be connected to base stations for different public networks (ISDN, PSTN, etc). We initially built an ISDN system for demonstration. The demonstration of a prototype for PSTN was configured with small effort. Changes to ADSL will also be fast. Incorporation of new DECT modulation schemas and use of 2.4GHz frequency[3] are mainly software upgrades, only involving minor changes in the hardware.

- Wireless LANs, wireless extensions to wired LANs and wireless data communication through public telephone networks are addressed in the same system.

DECT is only a radio access technology. We use it for data transmission, both in local area networks and public networks. Adopting DECT for local area networks, in spite of its current speed limitations, means to offer today, an additional feature to SOHO applications. We also think that in a more long-term scenario, with the foreseen improvements, DECT will continue to be competitive.

Standardization activities

HIPERLAN [8] is designed for operation in two distinct frequency bands. In the 5.15 GHz to 5.25 GHz band (HIPERLAN 1), a bit rate of 25 Mbps is provided. The second band (HIPERLAN 2), ranging from 17.1 GHz to 17.3 GHz, will permit 100 to 150 Mbps.
HIPERLAN 1 is a fully decentralized network, supporting ad-hoc mobile communications. All mobile hosts communicate, sharing a single communication channel. Therefore, a mobile terminal cannot transmit and receive at the same time. When mobile hosts want to transmit, a contention-based protocol is required. A different approach from Ethernet (listen-while-talk) is needed. The proposed protocol is a variation of the CSMA protocol.
HIPERLAN 1 defines physical and MAC layers. The MAC layer provides mobility and equipment interoperability features, and ensures a level of security equivalent to the wired LANs.

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[3] A derivative from DECT (WDCT) operating at 2.4GHz ISM band, patented by Siemens, already exists for the US and Japan

HIPERLAN 2 is to be compatible with Wireless ATM. It utilizes a centralized MAC protocol. The IEEE 802.11 standard [9] for WLANs can be compared to the 802.3 standard for Ethernet LANs. It addresses the Media Access Control - Physical layers (MAC-PHY) level. The fundamental access method is a variety of CSMA/CA, with acknowledgement scheme. A variety of physical layers is supported, including diffused infrared (DFIR), direct sequence spread spectrum (DSSS), and frequency hopped spread spectrum (FHSS). Both spread spectrum techniques are used in the 2.4 GHz. Data rates of one Mbps and two Mbps are available.

IEEE 802.11 adopts base station oriented architecture. The total area is divided into cells, each one covered by a base station. IEEE 802.11 was approved at the end of 1997.
The Wireless ATM Forum working group, formed in June of 1996, is developing a set of specifications for wireless ATM systems. The reference model and the protocol architecture are specified. Requirements [10] for the PHY, MAC and DLC layers are identified.

The expected frequency of operation depends on national and international regulatory bodies. For the in-building scenario different choices are foreseen: in Europe, HIPERLAN 2 frequency band and in the US the unlicensed 5GHz band. For higher data rates a possible choice is the 60GHz band. For low cost ATM solutions, 25Mbps have been approved. In the 60GHz band, with a bandwidth of 5GHz, 155Mbps are achievable. The MAC protocol has to provide guarantees for both isochronous and asynchronous traffic types, and to provide support for standard ATM services. The available options for error control procedures of the DLC layer include error detection/retransmission protocols and forward error connection methods.

Paper Structure

This introduction presented an overview of the wireless communications subject, describing existing alternatives and standards. Section 2 presents in detail the DECT technology employed in our work. The system architecture is the subject of section 3. Sections 4 and 5 describe in detail the implementation, characterizing the hardware and the software. Finally, section six presents some conclusions.

2. DECT

DECT (Digital Enhanced Cordless Telecommunications) is a standard specified by ETSI (European Telecommunications Standard Institute). Originally called Digital European Cordless Telecommunications, it was first developed in Europe. Table I presents some characteristics of the DECT standard.

Table I DECT basic characteristics

Frequency band	1880-1900MHz
Number of carriers	10
Carrier spacing	1728MHz
Access technique	TDMA, TDD, FDMA
Traffic duplex channels	12
Data rate per channel	32kbps
Range	30m or 300m

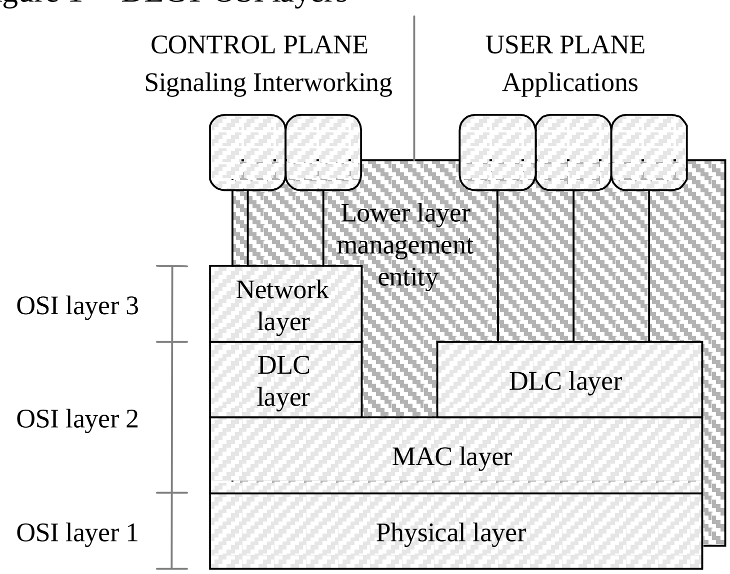
Modulation	GMSK (BT = 0.5)
Sensitivity	-86dBm at 0.01BER
Average RF power/ slot	10mW
Peak RF power	250mW

DECT is a micro-cellular system, consisting of base stations (FP – Fixed Part) and portable terminals (PP) for data or voice. In each cell exists a base station, which can serve several portable terminals. DECT defines the radio interface between the base station and the portables. It can be used as a single cell cordless system for SOHO applications or as a multiple cells system for larger area coverage.

DECT relies on a decentralized channel allocation procedure, called Dynamic Channel Selection (DCS). Instead of having fixed channels, the portable terminal is continuously scanning the available channels, trying to use the best one. The channel to be used is not defined by the base station. The DECT portable terminal chooses the channel among the 120 existing channels, taking the least interfered channel from its channel list. The list is periodically updated. The set-up of new channel takes in account the local interference situation. Set-up is achieved for new connections or for handovers. DECT has the ability to handover time slots, in a seamless way, to improve communication quality.

DCA (Dynamic Channel Allocation) gives an additional capacity compared with cellular systems using fixed channel allocation mechanisms. There is no need to plan the system because it adapts itself to environment conditions. Different applications and different operators can dynamically share the DECT spectrum, without prior channel allocation to specific services or base stations.

Figure 1 -- DECT OSI layers

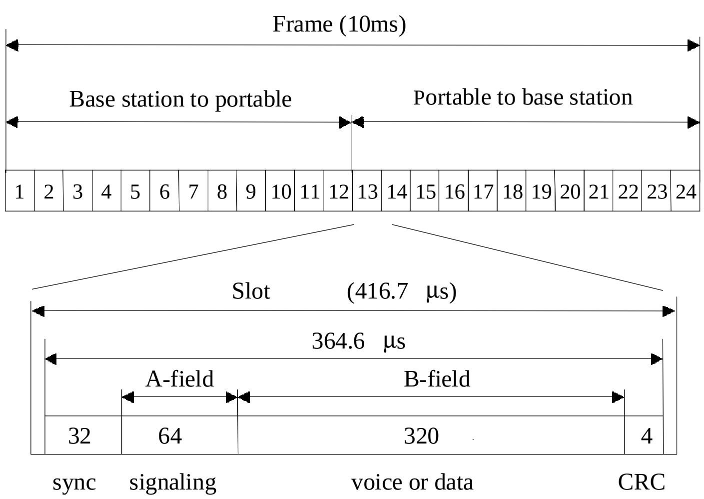


The architecture of DECT protocol is closely related to the lower layers of the OSI reference model, as presented on Figure 1. DECT has a physical layer, a data link layer, and a network layer. The data link layer is composed of a MAC (Medium Access Control) layer and a DLC (Data Link Control) layer. The DLC layer is divided in two planes, the control plane for signaling and interworking, and the user plane for transfer of user information. LLME (Lower Layer Management Entity) is a management entity that spans a number of lower layers and is used to describe all control activities, which do not follow the rules of layering.

Physical layer

The Physical layer specifies radio parameters such as frequency, timing and power values, the bit and slot synchronization, and the transmitter and receiver performance. The DECT physical layer employs TDMA (Time Division Multiple Access), TDD (Time Division Duplex), and FDMA (Frequency Division Multiple Access). DECT operates in the 1.88-1.90GHz band, which is split into 10 frequencies of operation (MC – Multiple Carriers). With FDMA, one out of ten frequencies will be employed in each channel. The signal is modulated with GMSK (Gaussian Minimum Shift Keying). GMSK is a MSK modulation technique in which the data bits are first passed through a Gaussian Pulse Shaping filter.

Figure 2 DECT frame



Within the 10ms TDMA frame (Figure 2) there are 24 slots. The 24 slots are divided into two groups of 12 slots. One group is employed in forward transmission and the other in reverse transmission. A duplex channel is a pair of one slot for transmission and another for reception (TDD). As the slots in the TDMA frame need not be transmitted on the same frequency, 12 slot pairs and 10 frequencies give rise to 120 independent channels. Current DECT implementations, due to hardware limitations, can not use of the 120 channels. In fact, available synthesizers for RF modules can not switch to a different frequency during the interval between slots (50µs). Therefore, for each of adjacent slots, one is not used. It is called a *blind slot*.

The radio receiver sensitivity shall be –86dBm, or better. It is defined as the power level in the receiver input at which the Bit Error Rate (BER) is 0.001.

MAC layer

The MAC layer specifies logical channels. It also specifies how logical channels are multiplexed and mapped to the physical channels. The MAC layer basically provides channels for signaling information to the C-plane (paging and control). These channels are mapped to the A-field. The normal bit rate of a channel for user information is 32kbps, which corresponds to 320 bits of useful information (B-field) in 10ms (Figure 2). As only four bits are used for error correction (X-CRC), which is not enough for data transmission, DECT provides another format, named protected B-field (Figure 3).

The protected format divides the B-field into sub-fields. The last four bits are always the X- CRC bits. The other bits are divided into sub-fields of 80-bit length, where the first sub-field starts with the first bit in the B-field. The sub-fields are numbered B0, B1, B2, etc. All 80 bits sub-field consist of a 64 bit data block followed by 16 bits of CRC (R-CRC).
Protected B-field reduces data transfer speed to 25.6kbps. To obtain higher speed, multiple user information channels can be employed. For example, to provide DECT access to ISDN, using 64kbps, three DECT channels are necessary.

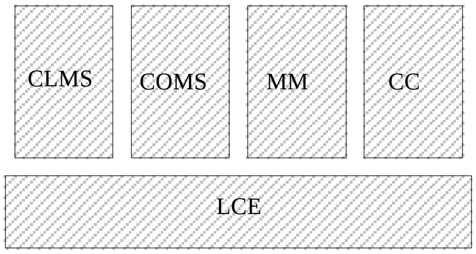
Figure 3 Protected B-field

64		324								
A		B								
		B_0		B_1		B_2		B_3		X
data	R_A	data	R_{B0}	data	R_{B1}	data	R_{B2}	data	R_{B3}	X
48	16	64	16	64	16	64	16	64	16	4

DLC layer

The DLC layer specifies services for the C-plane and for the U-plane. For the C-plane, a point-to-point service and a broadcast service are defined. The point-to-point service can operate in acknowledge or unacknowledged mode and provides addressing, frame delimiting, error control, flow control, segmentation of network layer information fields, fragmentation of DLC frames and connection handover. For the U-plane, the transparent unprotected service, the frame relay service, the frame switching service, and the rate adaptation service are defined. Data rates at DLC layer for U-plane are 32kbps or 24kbps per channel, depending on the use of unprotected or protected B-field. Unprotected B-field is used for voice communication in ADPCM format. Two bytes used at DLC layer reduce data transfer from 25.6kbps to 24 kbps.

Network layer
Figure 4 Network layer entities

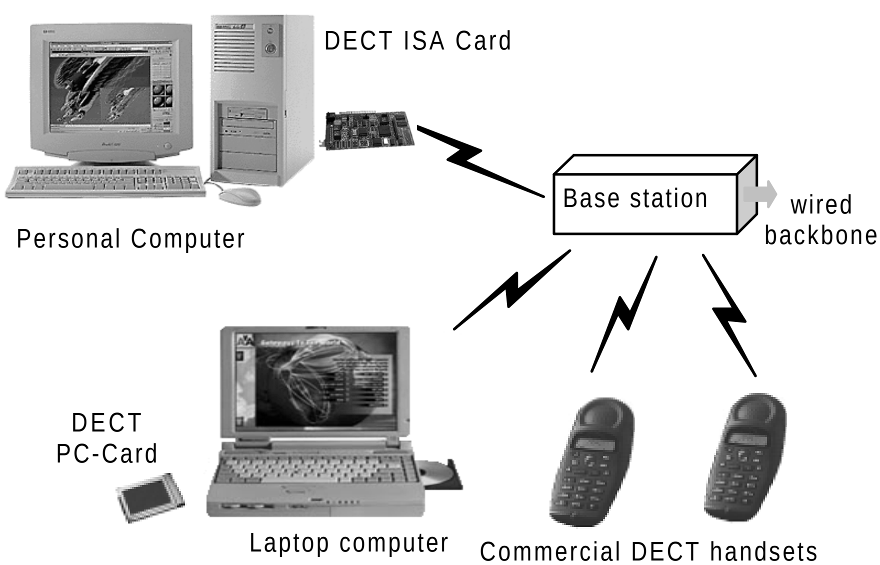


Network layer consists of several entities, as shown on Figure 4. LCE (Link Control Entity) defines an interface between DLC layer and CC (Call Control), MM (Mobility Management), COMS (Call Oriented Messages Services), CLMS (Connection-Less Messaging Services) entities. LCE is responsible for the establishment of connections when messages need to be sent to the DLC layer.

DSP services

The DECT standard contains a large number of features. Only a subset of those features is appropriate for a given application. To apply the standard to a specific application, it is necessary to specify the specific subset. This definition is called a profile. The objective of the DSPs (Data Services Profile) is to make inter-operability possible between FP and PP for non-voice applications. To meet the wide variety of possible applications six principal types of service are defined (A to F). Type A is a low speed frame relay with a throughput of up to 24kbps, employing only one DECT channel. Type B is a high performance frame relay with a throughput of up to 552kbps (23 slots), using asymmetric connections. Since equipment conforming to the DECT DSPs can be used on different contexts, two classes of mobility support are defined. Class 1 is used in local area applications, for which terminals are pre-registered with one or more specific base stations. Class 2, provides roaming, for public and private applications.

Figure 5 Generic system architecture



3. GENERIC SYSTEM ARCHITECTURE

The architecture of the generic system includes components to build SOHO (Small Office/Home Office) wireless applications, with or without a wired backbone (Figure 5). The backbone is not part of the generic system. Applications have been configured using Ethernet and ISDN (Integrated Services Digital Network) networks, as backbones. The generic system consists of a base station, supporting voice and data communications, data terminals and phones. Commercial DECT phones, GAP (Generic Access Profile) compliant, are adopted. Users, in the system range can make internal calls or external calls through the public or local area network.

Base station

The base station can be connected to different networks, like a LAN or a public network. If no connections exist, the standalone base station only allows internal communications. An example of a standalone system is a WLAN where several PCs can communicate among themselves. The base station can accept six duplex channels. Channel data rate is 32kbps. ADPCM (ADaptative Pulse Code Modulation) for voice communication uses the 32kbps. For data transmission, a CRC is introduced and only 24kbps, per channel, is affordable. Therefore, multiple channels are needed to improve data rate. For ISDN connections, multiple channels will ensure 64 or 128Kbps. We developed a base station with an ISDN interface to be connected to an ISDN NT (Network Terminator). It provides data and voice access to the ISDN network. Data communications, faxes, file transfer and Internet access are the services provided. For Internet access, the number of allocated DECT slots can depend on average data rate. Three slots are allocated for fax transmission.

For wireless LANs, 6 channels (6×24kbps) is the limit, using symmetric connections. To attain higher data rates, asymmetric connections can be used. Using asymmetric connections, at least one slot is necessary to receive acknowledgments. In this situation, using 23 slots, 264kbps (11×24kbps) can be achieved. For WLANs, we adopt a different approach. The base station is a DECT ISA card inside a PC. It can work as a standalone base station or can be connected to a LAN, acting as a wireless extension. For LAN extension, Windows NT and a network adapter (Ethernet, token-ring, etc) are also necessary. Extension of the LAN is done, using routing capabilities of Windows NT. Transport and Network layers are supported by Windows NT functionality.

Portable terminals

For voice communication, GAP DECT handsets are used. An increasing amount of commercial DECT phones is now available at the market**.** Data terminals are personal computers, such as desktop PCs that, in order to avoid cabling, are connected to the base station via radio. For that, an ISA card can be used. Further mobility is achievable through the use of laptops or notebooks equipped with a PC-Card. A standard protocol for data, as GAP for voice, is not yet approved. Therefore is not yet possible to use terminals and base station from different manufacturers.

4. HARDWARE

Figure 6 ISA board

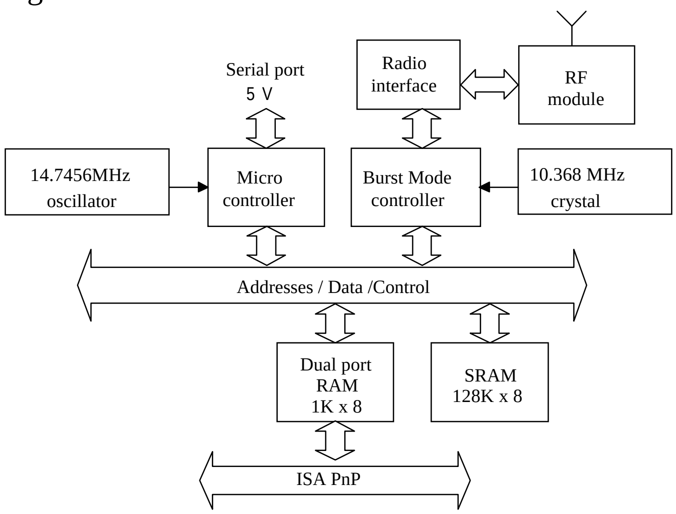
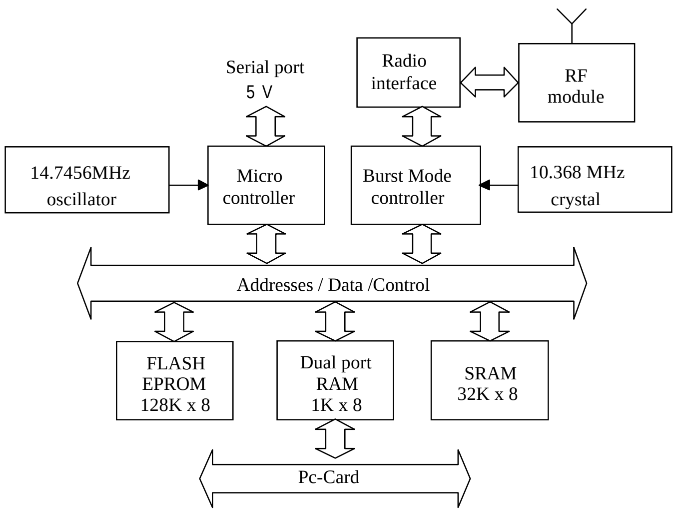


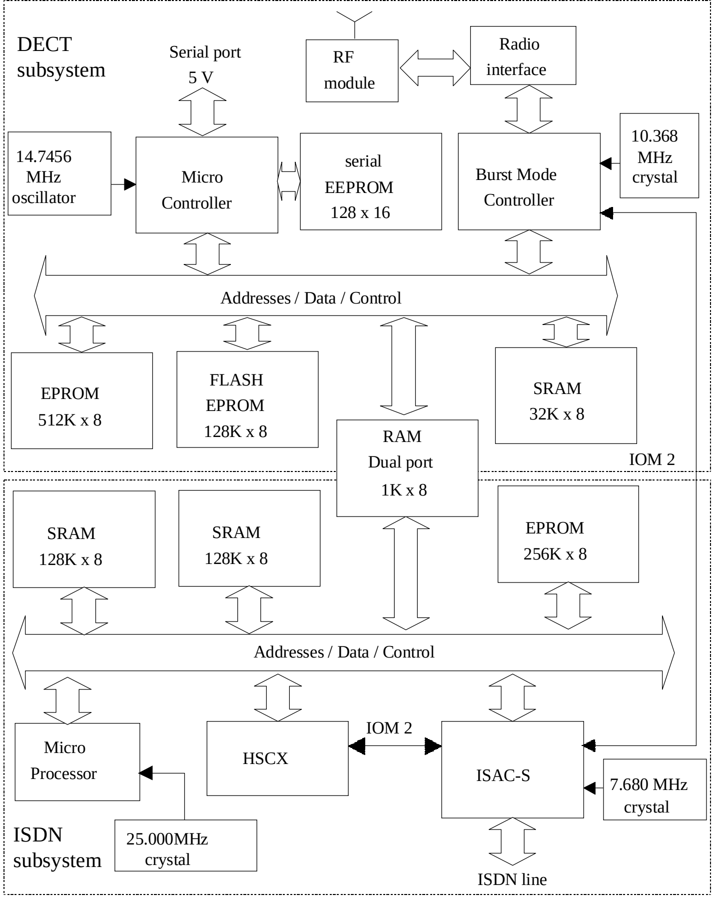
Figure 7 PC-Card



ISA card (Figure 6) and PC-Card (figure 7) have identical architectures. The main difference lies on the base band processor (BMC - Burst Mode Controller). The BMC on the ISA card has a larger internal RAM, allowing a more sophisticated program. Therefore, ISA card can also work as base station. Both cards incorporate a DECT RF (Radio Frequency) module, a DECT base band processor, a microcontroller, a dual port RAM, and RAM. PC-Card (type III) includes a flash memory where tuples for PC-Card initialization are stored, as well as, the program.

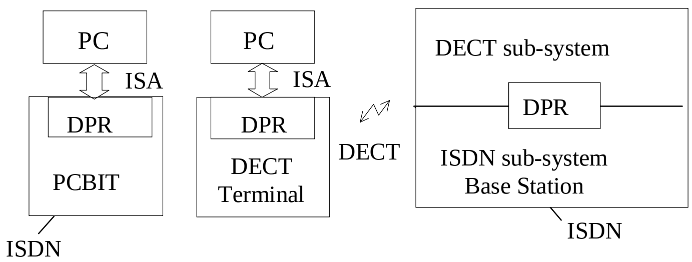
DECT/ISDN base station consists of two sub-systems cards (Figure 8). DECT sub-system is similar to the other cards. ISDN sub-system establishes and terminates ISDN calls, accomplishes ISDN signaling, formats data to be transmitted and received, and transfers voice from/to the IOM line. ISAC (ISDN Subscriber Access Controller) and HSCX (High-Level Serial Communication Controller Extended) integrated circuits are used. We use the architecture of an ISDN ISA card developed at INESC, named PCBIT.

Figure 8 ISDN card



In PCBIT (Figure 9), data is transferred from the PC to the ISDN line through the DPR. In the DECT/ISDN system, data is transferred from the PC to the ISDN line, using the DPRs of DECT terminal and base station and between them the DECT air interface. Therefore, the software for PCBIT (PC drivers) can be re-used. In addition, users previously using PCBIT can transparently use wireless access to ISDN.

Figure 9 Communication to the ISDN line



5. SOFTWARE

There is software common to the three cards. It implements the operating system, the physical and MAC layers of DECT protocol and the dual port RAM control. The DLC and Network layers, as well as, the Inter-working Unit (Figure 9) depend on the application, being different for ISDN and LAN applications.

Operating system

A kernel, written in Assembly language and based on [11], implements a very simple operating system (OS) that supports multitasking. The number of tasks is fixed, being defined at compilation time. Tasks are activated to process interrupts, whenever the active task sends or waits for a new message, and at the end of a nested interrupt. Task management is based on priorities.

Two types of tasks exist, having both a mailbox, for message communication, and a stack. Special tasks, activated to process interrupts, use reentrant procedures to allocate dynamic memory. Blocks of eight bytes can be reserved. Normal tasks do not use reentrant procedures, but can allocate any number of bytes. The existent 128 timers can be requested to the operating system, indicating an identity number, the waiting time and a mailbox. The timer expiration message will be sent to the mailbox. The interrupts, generated at the end of each DECT frame, with a periodicity of 10ms are used to activate tasks and to update timers. The OS also provides procedures to read and program the serial EEPROM, existent in the base station board and to communicate through the serial port (19200 baud).

Physical layer

The RF module and Burst Mode Controller (BMC) implement the physical layer. The RF module receives and transmits data in a serial format. BMC codes and decodes this format. Code running in BMC supports simultaneous management of six DECT channels (bearers). In the base station, it offers procedures to manage dummy bearers, used to transmit basic system information. Routines to search and synchronize channels are offered in portable terminals. BMC incorporates a RISC processor. As program memory of the RISC processor only contains 255 instructions and conditional jumps do not exist, dynamic replacement of code was implemented. RISC program communicates with DECT microcontroller, using shared memory.

MAC layer

MAC layer software involves BMC management, portable synchronization, portable access control, slot/carrier scanning and handover. As it controls directly the hardware, code is mainly written in Assembly language.

The MAC layer is implemented using two tasks. A normal task executes isochronous operations and a special task the synchronous operations.

BMC management

BMC management is the most critical part of the program, specifically in the base station. Each 10ms, the DECT frame period, received data must be read from active slots, and data to be transmitted in the next frame must be updated. In the base station, during the frame period, it is also necessary to update the frame counter, and to prepare control messages. These messages are multiplexed in the A-field (see Figure 2). Messages contain information about base station capabilities, active slots, slot and carrier identification, current frame number and indication of existent calls to PP.

Portable synchronization

PP (portable part) initiates the establishment of a communication, but for that, it needs to be synchronized with a base station. To allow PP synchronization, base stations are continuously broadcasting information, in the A-field, regarding its identification and its operation. Therefore, a bearer (channel) to convey this information is always needed. If no traffic bearer is present, a dummy bearer, only containing the A-field, will be established. During synchronization, PP looks for active channels in order to synchronize with the base station. It analyses the signal power in every channel (all slots and all carriers), registering RSSI (Radio Signal Strength Indicator) values in a table. The table in scanned in a downward manner to find a channel for synchronization. Beginning with the first table element (with the highest RSSI), PP activates reception on this channel. When synchronized, it checks the messages in the A-field to identify the base station (RFPI- Radio Fixed Part Identifier). If PP is registered in this base station, final synchronization is initiated. If not, it activates reception for another channel from the table, trying to find a valid base station. After having found a valid base station, the PP analyses information sent by the base station in order to obtain the slot, carrier, frame and multi-frame identification. Only after this procedure, it is possible to establish a connection.

Portable access control

After being synchronized, the PP chooses the best channel (lowest RSSI) to establish a connection. It maintains a table with RSSI values that is continuously updated. To establish a connection on the chosen slot/carrier pair, PP must wait until the base station processes this carrier. In fact, the base station checks requests for PP connection establishment, only for one carrier during each frame. The identification of the carrier being processed is sent in the A-field on a broadcast channel. Therefore, PP knows when is the correct time to request a connection. In the base station, every slot of the processed carrier is analyzed to check for broadcast messages. If a request for connection is received, a confirmation indication is prepared. As an interrupt is generated at each slot, base station software involves more processing than PP software.

Handovers

Sometimes, after a connection is established, signal quality decreases due to interference, noise or distance increase. When this happens, the system can change the slot/carrier pair (physical channel). The change of the physical channel for the same logical connection, in order to obtain better quality in the communication, is a bearer handover. The criteria to initiate an handover is based on the signal power (RSSI) and number of errors (BER- Bit Error Rate), during transmission and reception. In a seamless handover, the user will not be aware of the change. For voice, two connections are maintained during a small period, being the voice transmitted over both bearers. As data is transmitted using packets, it was decided to disconnect the first channel before establishing a new connection.

Slot/carrier scanning

As referred, PP maintains a table with RSSI values and uses it to choose the channel to request the establishment of a connection. The table is also used for bearer handover. In order to maintain the table updated all the slot/carrier pairs should be periodically (20ms) scanned. This is done, activating the reception in each slot, for each carrier. To avoid interference with active channels they are ignored during slot/carrier scanning. In fact, they can not be used to establish new connections.

Upper level layers

Different approaches are adopted in the software development for the DECT/ISDN system and WLAN. Software for upper level layer, in the ISDN system runs on the DECT microcontroller and in WLANs on the PC.

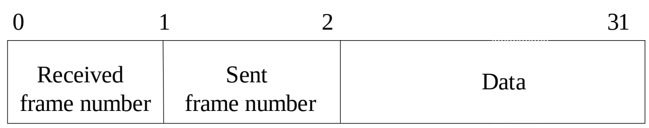
ISDN system

Software to implement the complete stack of DECT layers, specifically DLC for data transfer (user plane) is time consuming and can not be afforded by the microcontroller currently used. Therefore, only DLC layer, Network layer and Inter-Working Unit (Figure 1) for voice are implemented. They only implement GAP protocol functionality (control plane). For data, DLC, Network and Inter-working Unit functionality is implemented, without using DECT primitives. For data transfer, a specific protocol is developed. DLC layer, Network layer and Inter-working Unit, for voice, are implemented as three independent tasks. Another independent task manages ISDN calls, checking ISDN connections status and informing Inter-working Unit. The informing Inter-working Unit forwards the information to the Network layer.

The implementation of all entities on the Network layer is not mandatory. Only CC and MM are implemented. They are necessary to support GAP protocol. CC allows establishment, maintenance, and release of services. One of the MM responsibilities is to verify access rights to the base station.

DLC layer primitives of user plane are not supplied. However, functions to solve problems caused by damage, lost and duplicate frames are implemented. Frames, with 32 bytes, have the format of Figure 10. A frame sent from A to B has a field identifying itself (frame number), and a field to acknowledge the last frame from B. Sent frame number enables re-ordering of frames when retransmission is necessary or when, in order to improve data rate, multiple DECT physical channels are used. Received frame number permits the sender to decide if retransmission is necessary. As only 30 bytes are effective transmitted data, the data rate for each DECT channel, using protected B-field) will be 24kbps (8×30bytes/0.01s). Using DECT DLC primitives, 24kbps are the available bit rate.

Figure 10 Frame format



WLAN

For wireless LANs [12], DLC and Network layers are part of the PC driver, and consequently are executed on the PC. Type B services and class 1 are implemented, using LU2 service and frames FU6 [13].

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Intermediate and Miniport drivers were developed [14]. As DECT card is installed as an Ethernet network adapter, the intermediate driver translates from Ethernet protocol to DECT protocol. The Miniport driver is responsible to directly manage the network adapter hardware (ISA card or PC-Card). The Miniport driver implements the DLC DECT layer, using the NDIS library [15]. Miniport driver performs the communication with the DECT card, via the RAM dual port and the interrupt line. NDIS provides general functions, like synchronization and queuing. Miniport driver encapsulates data in DECT packets and sends them, through NDIS, to the DECT card. In the opposite direction, when the DECT card receives data, it indicates the existence of a data packet and sends it to the DECT driver, via NDIS. The driver de-encapsulates data and sends it to the transport driver via NDIS.

Dual Port RAM control

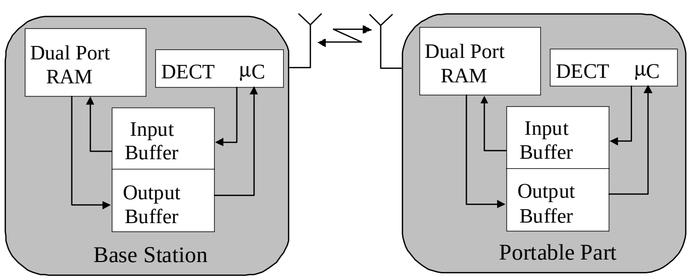
Table II Dual Port Memory structure

Number of bytes	Structure	
	Base station	PP
511	Output data	Input data
511	Input data	Output data
1	PC or ISDN control	DECT control
1	DECT control	PC control

During each DECT frame, it is necessary to transfer data between the DECT microcontroller and the PC (ISA and PC-Card), or between DECT subsystem and ISDN subsystem (DECT/ISDN base station). The transfer is through the dual port RAM (DPR). Interrupts signal the existence of new data in DPR. DPR is organized as presented on Table II. Control bytes include the number of last sent message, the number of the last received message and two flags. One flag indicates the existence of an error and the other permits the reset of the card. When data is written in the dual port RAM, the corresponding control byte is updated and an interrupt to the processor connected to the other port is generated. When data is read by the receiver, it indicates to the sender the number of the message read, writing this information on the corresponding control byte.

Data transfer uses buffers between DPR and the microcontroller as presented on Figure 11. Both sides of communication have an identical architecture with input and output buffers. Each buffer has 100 blocks of 30 bytes (see also Figure 10). When the last block is used, next data will be put in the first block.

Figure 11 Buffers for data transfer



Field measurements

Field measurements were performed to estimate the performance of the system (radio interface) for different distances, inside and outside the building and with and without movement. The numbers of bytes sent as well as the number of retransmitted bytes were calculated in the DLC layer at the base station. Tests were performed downloading files from the Internet. We chose the base station to run the evaluation program, due to the asymmetric nature of Internet connections where the information is transmitted from the base station (Internet Service Provider) to the portable terminal (PC). Two situations were considered, one inside the building and in the same floor, and the other, outside, in the University campus maintaining the line of sight. For the measurements outside the building, we maintain the base station in the building near a window. Inside the building we tested communications in the same room (A1), moving to 10m (A2) and 15m (A3) away in line, and finally we stopped at that last point (A4). In the campus, measurements were done, moving and stopping at different distances: 15m stopped (B1), 15-70m walking (B2), 70m stopped (B3), 110m stopped (B4), and finally when line of sigh was lost (B5). Table III and Table IV present the number of bytes sent and lost for the different situations. The last lines of the tables present the ratio of retransmitted bytes.

Table III Field measurements inside de building

Inside the building, in the same floor							
A1		A2		A3		A4	
8k	0	8k	283	8k	523	9k	80
9k	0	9k	276	9k	745	7k	0
8k	0	8k	239	8k	300	8k	30
0%		3.2%		6.3%		0.5%	

Table III Field measurements in the campus

Outside de building, in the campus									
B1		B2		B3		B4		B5	
59k	210	83k	630	44k	0	66k	690	18k	180
43k	0	38k	180	64k	0	92k	90	85k	30
41k	0	2k	0	73k	1110	104k	90	13k	1620
0.15%		0.66%		0.61%		0.34%		1.6%	

Comparing situation A with situation B, it is clear that when the portable and the base station are in line of sigh, the number of bytes, lost in the air interface, is smaller. There were not problems with distance because, in this experiments, the limit of distance of the DECT standard (300m) was not attained. We also concluded that, when moving, there are more retransmissions (A2, A3 and B2) that do not depend on distance. Looking at Table III, we can see that the retransmission ratio is higher when movement exist. Looking at Table IV we also see that errors occur in bursts (B3, B4 and B%) probably due to interference.

6. CONCLUSIONS

We presented a generic wireless system, for which we adopted the DECT air interface. It can be used to build low cost applications for SOHO (Small Office/ Home Office) usage. The system consists of one base station, voice terminals, and data terminals. The base station takes care of switching the calls internally and/or externally if the base station is connected to a network. Voice terminals are commercial DECT handsets. Data terminals are PCs equipped with a DECT PC-Card or a DECT ISA card.

For demonstration, we built three systems using the generic system: the DECT/ISDN system, the DECT/Ethernet LAN, and the DECT WLAN. DECT/ISDN base station card, besides the DECT part, includes a sub-system, defining the interface to the ISDN line. The WLAN base station is a PC equipped with an ISA card, just like the desktop PC acting as wireless terminal. The difference depends on the running software. In the DECT/Ethernet LAN, the base station ensures the connection to the Ethernet network. It also includes an Ethernet network adapter. Windows NT routing capabilities are used to connect DECT to Ethernet cards.

Current achievable data rate varies from 24kbps till to 264kbps. With only one bidireccional DECT channel, data rate will be 24kbps. If we use 11 channels in one direction and only one for acknowledgment (asymmetric connection), 624kbs are attainable. Evolution on RF hardware, specifically on synthesizers, will make possible the use of the 24 slots of DECT standard. If an asymmetric communication is establish with 23 slots, 552kbps (23×24kbps) can be attained. The use of DECT currently limits the data rate of the system. However, DECT is a well-established technology, with low prices, that has recently included additional modulation schemas for high-speed, up to 2Mbps.

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