A SOLUTION FOR AN IP/ETHERNET RADIO: CONCEPT AND IMPLEMENTATION OF A TECHNOLOGICAL DEMONSTRATOR

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Abstract: A working demonstrator for an IP / Ethernet radio link is presented. It can transport simultaneously legacy E1 and Ethernet traffic in the 23 GHz frequency band by means of adaptive modulation. Thanks to a proprietary mechanism the adaptation is driven by the quality of the remote receiver through feedback channel and is completely error free. Architectural and implementation concepts are explained. A complete set of measurements is detailed.

Keywords: availability, communication networks, communication systems, digital radios, modems, modulation.

1. INTRODUCTION

The evolution of cellular networks, beginning with the so called 2.5 generation technologies (GPRS), is clearly in the direction of increased data traffic versus voice traffic or in other words packets switching instead of circuit switching. The introduction, with the third generation, of high-speed data applications over new radio access technologies like HSDPA / HSUPA (High Speed Downlink Packet Access / High Speed Uplink Packet Access) has led to a rapid growth of the backhaul traffic volume and it will increase still further. At the same time the revenue-per-bit generating potential of the new applications is much lower than it used to be for traditional services, such that the cost of transmission cannot grow proportionally to the transmission speed.

Microwaves radio links are a valuable option for the backhaul infrastructure, but to follow the evolution they need more flexibility, increased bandwidth, variable throughput and low cost.

The input interface has to be configurable with a mix of E1 lines and Ethernet data traffic. The bandwidth has to be increased without increasing the cost of the microwave radio parts.

Cost-per-bit enhanced microwave systems with adaptive coding and modulation provide affordable bandwidth for data applications. Defining different classes of traffic it is possible to design a link for high quality traffic and provide a data traffic reserve with reduced availability and less guaranteed delay.

Adaptive modulation is suitable for data applications but it is not restricted to Ethernet interfaces. It is possible to apply adaptive modulation also to legacy-style pure E1 interfaces by defining high priority E1 lines (to guarantee connection) and low priority E1 lines: lower priority lines are dropped when the link capacity is reduced.

2. HARDWARE STRUCTURE

The Carrier Research and Development Microwave department of Siemens Network S.p.A. in Cassina de' Pecchi (Milan Italy) developed a technological demonstrator to transport simultaneously data packets traffic (Ethernet) and voice E1 traffic on a wireless connection with a low cost radio link.

Figure 1 : Modem and Ethernet Access Units

The support of mixed E1 / Ethernet interfaces and the implementation of sophisticated QoS (Quality of service) mechanisms in the embedded Level 2 switch

guarantee that end to end transmission fulfils the Mobile Radio Access Network (RAN) requirements in all conceivable scenarios.
Figure 2 shows the most important blocks of the system. It is composed by an Indoor and an Outdoor Unit.

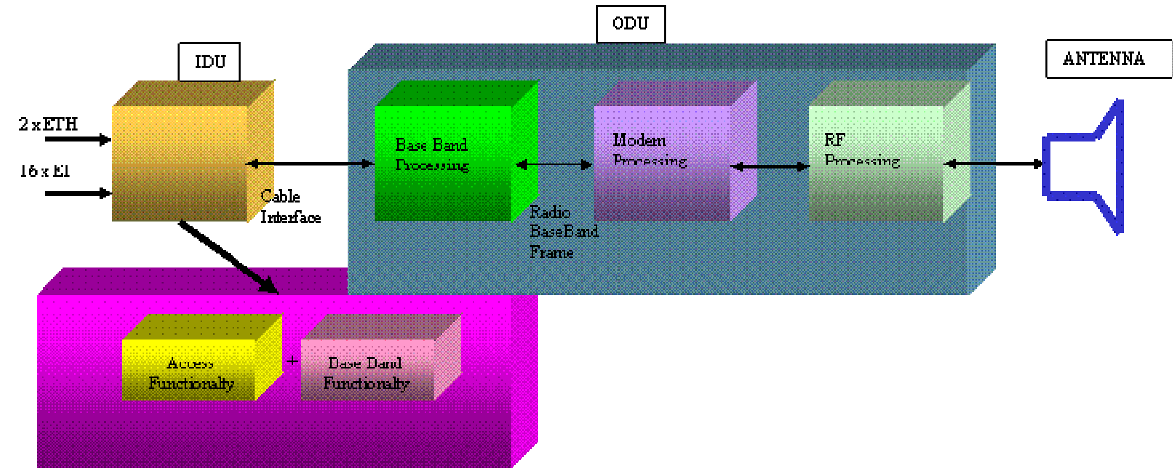

Figure 2 : System Block Diagram

Modulation Format	Available Bandwidth [N = E1 Equivalent Capacity]	Payload type
16 QAM (full capacity)	32 x E1 N = 32	E1 number = k, k = 0 ÷ 16 Fast Ethernet E1 Equivalent capacity j = 32 – k
4 QAM (half capacity)	16 x E1 N = 16	E1 number = k, k = 0 ÷ 16 Fast Ethernet E1 Equivalent capacity j = 16 – k

Table 1 : Modulation Format vs. Available Bandwidth

The Indoor Unit is responsible to manage the access and the base band processing.

Figure 3 : Indoor Unit (fully equipped)

The demonstrator works in two different modulation formats. In Table 1 is reported the behaviour in both cases.
The access unit manages up to 16 E1 channels and 2 Fast Ethernet ports.

As reported in Table 1 using the 16 QAM modulation format, the system can transport 32 x E1 equivalent capacity shared between E1 channels (for a maximum values equal to 16) and Ethernet traffic. It is possible to chose the E1 number, named k, with a programmable configuration and the remaining bandwidth (j = 32 - n) is used for the Ethernet traffic

with a priority mechanism that is described in the following section.
When 4 QAM modulation format is used, the most robust modulation, the available bandwidth is half of the previous case (16 x E1 equivalent capacity).
Thanks to the modulation adaptation, it is possible to generate a priority mechanism for the traffic. In fact, the most E1 precious traffic is transported in both modulation formats and then it is always transmitted. In normal environment condition, the system works as 16 QAM and all the traffic is transmitted. When there is a fading on the radio channel due to the propagation conditions, the system automatically changes the modulation towards the most robust 4 QAM without errors. The switch is hitless for both traffic types, E1 and Ethernet. The planned traffic for the 4 QAM is always transmitted while the remaining less precious traffic is lost in this modulation format.

The Outdoor Unit (Figure 4), placed near the antenna, includes the modem (Figure 1) and the microwaves parts.

Figure 4 : Outdoor Unit

Adaptive modulation is not a new idea (see for instance (Cavers 1972)), but it was seldom used in digital radio links.

Adaptive modulation requires some kind of end-to-end signalling to synchronize the physical mode on both sides of the link. Link control is inherently related to the concept of “radio frame”, that is a frame structure deliberately designed to manage the instantaneous physical layer properties of the link. Note that generally speaking in conventional point-to-point microwave radios the frame structure is not perceived at the level of mo-demodulation processing, but only at data interfaces.

Each radio frame has an overhead portion to accomplish at least the following three tasks:

- detecting frame boundaries
- identifying the physical mode associated with the current frame
- sending physical change requests to the remote modem.

The overhead must be minimized to enhance spectrum efficiency, but if the frame is too long the system is slow to react to channel impairments. We chose a frame length of 1.5 msec like a trade off between adaptation speed and spectrum efficiency. The system is fast enough to track a fading of 100 dB per sec with an overhead of less than 0.5 per cent.
The preamble is composed by 16 QPSK symbols that form a 32 bit unique word for frame alignment and 112 BPSK symbols for signalling. The signalling information is composed by 48 bits that are coded with a (7, 3) *maximal-length* block code. Maximal-length codes are the dual of Hamming codes: a comprehensive explanation of this subject can be found in Clark and Cain (1981). This coding scheme has good performances thanks to soft quantisation. The latency is very low, so the information about the physical mode can be used immediately. The complexity in term of equivalent gates is very small.
The payload uses QAM modulation formats. For this demonstrator activity we tested only two modulation formats: 4 and 16 QAM, but the radio frame and the modem have been designed to use also 32, 64, 128 and 256 QAM. The payload is protected with a Reed Solomon code that is able to correct burst errors up to ten bytes long. We chose this coding scheme to keep the latency low, so we excluded concatenating codes that require an interleaver to be efficient. Moreover we focused on validating the concept and the implementation on our radio, thus we used a decoder that has well known performance and low complexity. In any case the system is open to more efficient and complex coding scheme, like turbo codes or LDPC that are under study.
For the remaining digital parts of the modem we used intensively the large intellectual property base developed for the SCM chip described in (Schmidmaier *et al.* 2000). These include digital filtering, adaptive equalization, clock recovery, automatic gain control, automatic frequency control, carrier recovery with reduced sensitivity to the phase noise of the radio frequency local oscillators and other control loops. All of the digital processing is housed in two FPGAs (Field Programmable Gate Array).
The modulation format switching criterion is the measure of the channel quality performed by the demodulator. This information is inserted in the preamble and sent back by the modulator in the opposite direction, where the remote demodulator sends it to the base band, which has the responsibility of eventually dropping the low priority traffic. The variation of capacity is managed by the base band, the modulator changes its modulation format on a frame basis and the demodulator adapts automatically and with no errors (hitless). The system has been

measured to be able to follow effectively a fading increasing at 100 dB per second, performing the capacity adaptation with no errors.
This adaptive modulation changing is independent for the two directions, so that the data rate can be asymmetrical.
The transceiver operates in the 23 GHz band and has an operating output power of 15 dBm. It belongs to the Siemens SRAL XD family. Other members of the family are in the 7, 8, 13, 15, 26, 28, 32, 38 GHz bands. So the system can be easily extended to all other frequency bands.

3. ETHERNET SWITCH FUNCTIONALITIES

The access section is obtained generating a proprietary frame working at 155 Mb/s; it is the same SDH frequency, but it is a dedicated frame able to transport up to 64 x E1 channels. Figure 5 describes the logical partitioning of the functionalities mapped in a FPGA. Please note that here it is generated/analyzed a frame with E1 traffic and Ethernet traffic.

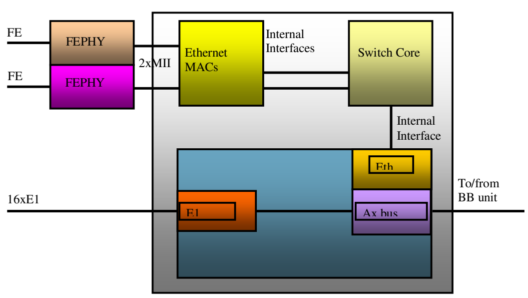

Figure 5 : Ethernet Access Block Diagram

The simplified block diagram of the most important logical functionalities mapped in an FPGA is described in Figure 5.
Figure 6 shows the switch management. The LAN ports available to the user are 2 x 10 / 100 Base T, but the system is open to further evolution.

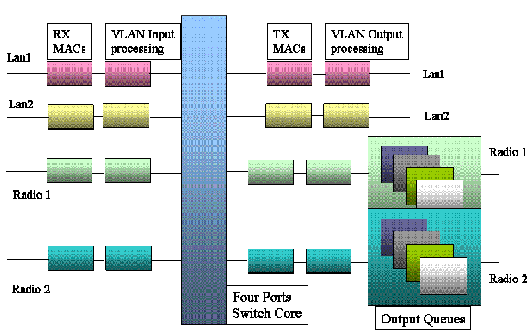

Figure 6 : Switch Functionalities Block Diagram

Ethernet traffic is classified in 4 queues according to the priority assignment criteria described in the following.

Each LAN port provides the following settings:

- Interface enable / disable
- Flow control enable / disable
- Maximum ingress rate limitation
- VLAN tagging enable / disable; if enabled Tag removal is applied (Trunk to LAN) and the following shall be configured:
  - VLAN ID
  - User priority
  - Tagging type: Overwrite, Double VLAN tagging (LAN to Trunk)

The priority assignment criteria are listed in priority order. Each criterion can be enabled / disabled and values associated to each one of the 4 queues can be configured. The priority assignment is independently applicable for each port while the last one, port priority is always enabled.
In the following list there are the criteria in priority order

- Destination MAC address
- Source MAC address
- VLAN identifier
- IEEE 802.1p (3 bit VLAN priority field)
- IPv4 (ToS or Diff-Serv)
- IPv6 (Traffic Class)
- Port priority

Each queue (1 to 4) is given a priority. Queues are served according to the following parameters:

Weighted Fair Queue (WFQ) with weights 8, 4, 2, 1 associated to queues from 1 to 4
Fixed Priority (FP): queue 1 has the highest priority

Please note that each LAN port interface can be enabled / disabled and there is an automatically Egress rate limitation; in fact the maximum value of the Egress rate is configured by embedded software according to radio capacity dedicated to Ethernet traffic and it shall be dynamically adjusted, when adaptive modulation changes radio capacity

The switch is able to learn at least 8192 MAC addresses; it is possible to manually configure up to 16 MAC addresses, named static entry. It is possible to configure an Aging time up to 15 minutes.
The whole VLAN addressing space (4096 values) is supported and 256 active VLANs are implemented.

Ethernet Switch is able to operate in different forwarding modes as described in the following list:

- Fully connected LAN ports / Isolated Radio ports
- Fully connected LAN ports / Fully connected Trunk ports
- Isolated LAN ports / Isolated Trunk ports

- Isolated LAN ports / Fully connected Trunk ports
- VLAN forwarding mode

Moreover for each port, LAN and Radio side, quite a lot of statistic counters are available for the performance of the Ethernet traffic. These counters are elaborated from the FPGA and the values are read by Control Unit by means a SPI (Serial Peripheral Interface) bus working at 4MHz.

4. MEASUREMENTS

In this section measurements performed on the equipment are presented.

4.1 BER / FER Curves

BER (Bit Error Ratio) of the E1 interface and FER (Frame Error Ratio) of Ethernet traffic are detailed in Figure 7 and Figure 8.

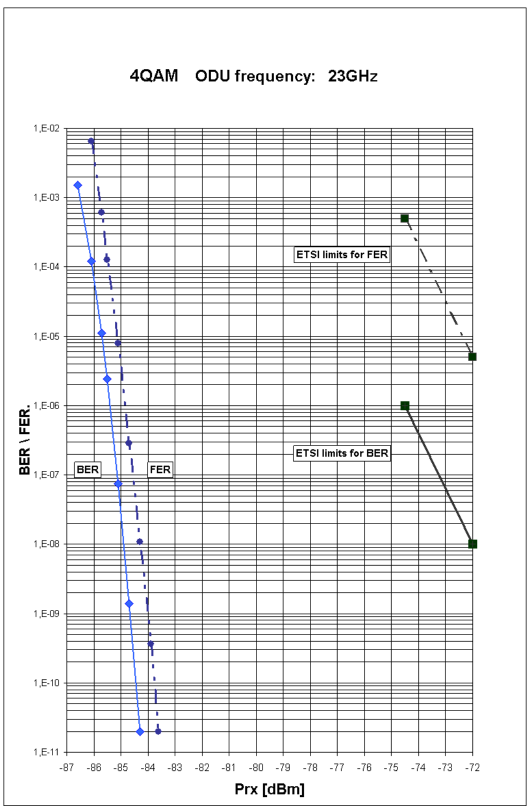

Figure 7 : 4QAM BER / FER

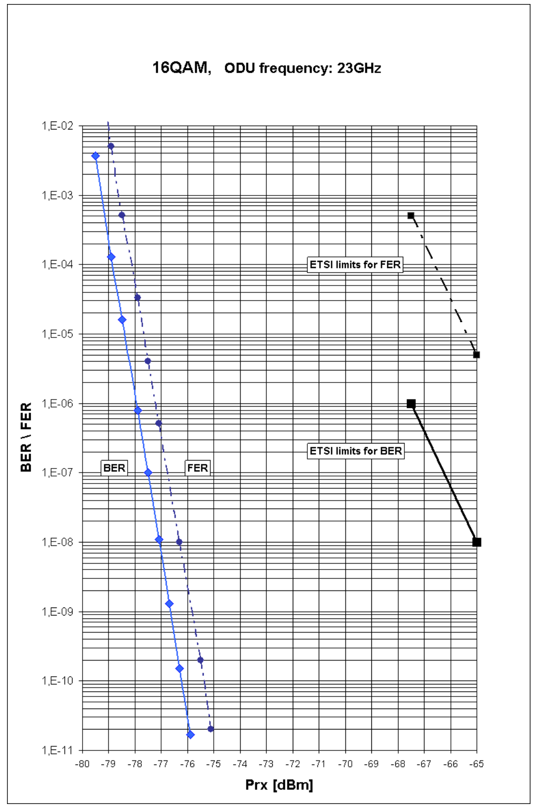

Figure 8 : 16QAM BER / FER

FER was calculated with frame size of 64 byte (Ethernet frame without preamble and Start Frame Delimiter SFD, with Frame Check Sequence FCS) as required in ETSI EN 302 217.
Curves are very steep, according to error-correction coding used and ETSI constraints are fully complied: a margin of 10 dB is achieved.
BER curve and FER curve are quite similar (they share the same slope) but they have a difference of about 1 dB. This difference has to be taken into account to set the modulation switch threshold that can vary depending on the type of traffic involved (E1 only / Ethernet only / both).
For more details see section 4.4.

Apart from BER / FER measurements also throughput and latency have to be considered to evaluate the performance of the system.

4.2 Throughput of LAN interface

When the LAN is set to work as a 10BaseT the throughput, expressed in percentage of port load is 100% both with 4 QAM modulation and 16 QAM modulation.

If the LAN is set as 100BaseT the throughput strongly depends on the modulation scheme used; in fact the maximum rate of the LAN interface is now 100 Mb/s and this value is more than the available radio channel capacity.

When full Ethernet traffic is selected (32xE1 equivalent capacity), the reference values for throughput, based on frame size of 1518 bytes, are:
32.8 % of ports load when 4QAM is used,
65.5 % of ports load when 16 QAM is selected.

Please note that to increase radio transport efficiency, most of all when the frame size is short, FCS is suppressed.

4.3 Latency

In Table 2 latency, expressed in milliseconds, is detailed.

Frame size [byte]	4 QAM	16 QAM
64	0.979	0.907
128	1.007	0.921
256	1.066	0.951
512	1.193	1.010
1024	1.449	1.141
1280	1.576	1.211
1518	1.703	1.270

Table 2 : Latency

Latency is defined by RFC 1242 and for store and forward devices is the time interval starting when the last bit of the input frame reaches the input port and ending when the first bit of the output frame is seen on the output port.
An important result is that 64 byte Ethernet frames share the same latency value of E1 traffic.

Please note that latency is very short, in order to be compliant with real time data constraints.
For example: voice requires latency less than 10ms and the values (of latency) reported above allowed the cascade of several equipment (in general three elements are taken into account during network planning).

4.4 Flat fading speed

Present implementation allowed modulation switch from 16QAM to 4QAM without errors with a flat fading with a speed up to 100 dB/s.
Being the modulation switch threshold configurable is possible to achieve fast speed, finding a trade-off between flat fading speed tolerance and propagation conditions in which the system works in 16QAM.

5. CONCLUSIONS

The feasibility of a configurable, mixed traffic, adaptive modulation, digital radio link has been proven. Prototypes have been built, using all compatible parts coming from standard production Siemens Networks S.p.A. radio system.
Measures have been performed both with legacy E1 data and IP / Ethernet traffic, with good results.
The system is open to evolution towards more complex modulation formats, more efficient codes and new Ethernet applications (for instance Gigabit Ethernet). It is planned to reach and exceed the capacity of 64xE1 equivalent channels over a 28 MHz radio channel, with a low cost compact radio.

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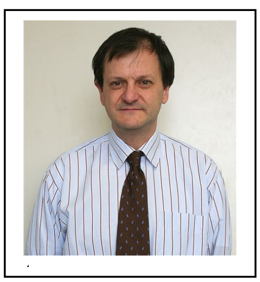
BIOGRAPHY

Sergio Bianchi was born in Pavia, Italy in 1957. He received the "Laurea" degree in Electronic Engineering from "Università degli Studi di Pavia" in 1983. He joined Siemens Networks S.p.A. (formerly GTE Telecomunicazioni) in 1984 and has engaged in research and development of radio modems. His research interests include modemodulation, digital signal processing and coding applied to digital radio links. He is author of papers and holds patents.

Andrea Dell'Orto was born in Merate, Italy, on July 9, 1972. He received the Doctor degree in Electronics in 1997 from the Politecnico University of Milan. In the same year he joined the R&D Transmission Laboratories at ITALTEL, presently Siemens Networks S.p.A., where he was involved in activities related with SDH Radio Systems developments. In 2000 he made two patents related to space diversity receiving technique.



Roberto Rezzonico was born in Milano, Italy, on April 16, 1963. He received the Electronic Engineering Doctor degree in 1988 from Politecnico University in Milano. In 1990, he joined the R&D Transmission Laboratories at Siemens Telecomunicazioni S.p.A., presently Siemens Networks S.p.A. where he was involved in activities related to digital processing signals in SDH and PDH Optical and Radio Systems developments. He is currently responsible for a Base Band laboratory in the Microwave Business Unit.