TRIAL LINK MEASUREMENTS ON AN ADAPTIVE MODULATION IMPLEMENTATION ON EXISTING PDH RADIOS

Massimo Grimoldi - Gianni Marion (*)
Paolo Agabio – Bruno Cornaglia – Stefano Veclani (+)

(*) Siae Microelettronica S.p.A.
(+) Vodafone Omnitel N.V

Abstract: This paper presents an implementation of the brand new adaptive modulation concept developed for existing PDH radios, namely dynamic modulation.
Filed trial measurements on a 23 GHz link with 4/16 QAM dynamic modulation are reported. The major result is that the link behaviour in general, and the modulation shifts in particular, were stable for the entire trial period and the link reliability is the same of a static modulation link.
Trial measurement analysis provides also a comparison between theoretical and measured link outage at 16 QAM modulation, and provides some hints in order to optimise operation of a link with adaptive modulation.

Keywords: Adaptive/Dynamic modulation, PDH, HSDPA.

1. INTRODUCTION

During the last years transmission capacity requirements in the mobile backhauling network (i.e.: the 2G network from the BSC to the BTS's and the 3G network from RNC to NodeB's) have been increasing very fast, and are going to grow in the near future due to performance improvement of HSDPA (High Speed Downlink Packet Access) and its evolutions (namely HSxPA).

With the development of HSxPA, there will be an increasing number of 2G/3G sites demanding capacities above 4 E1s and below 16 E1s, in order to provide peak capacity for HSxPA data services. This fact will have an impact on the entire backhaul network, comprising high hierarchy nxSTM-1 links (usually implemented with SDH radios) and low hierarchy feeder and tail links (usually implemented with PDH radios). While in the high hierarchy network it is cost effective to introduce external "packet switching" equipment (i.e.: ATM switches) in order to save radio link capacity, it is not cost effective to do the same in the low end of the hierarchy. Therefore, there will be a huge demand of radio capacity over traditional PDH links.
Moreover, PDH still represents the largest part of the access network for a mobile operator and this network is mainly deployed over crowded frequency bands (i.e.: 15, 18, 23 GHz). Therefore, the most efficient way to improve radio capacity is to increase spectrum efficiency implementing higher order modulations. This possibility is already available for PDH radios on the market, where modulation is often a software selectable parameter among 4, 16 and 32 states. Unfortunately, sometimes this possibility cannot be used due to a poor link budget margin that leads to reduced link availability. Adaptive modulation allows exploiting higher level modulations (e.g.: 16 or 32 QAM) also on these links, without the need of either link re-design or larger size antennas to be mounted.
Mobile operators are interested in the advantages provided by adaptive modulations on:

- existing PDH radios (current software configurable radios) where the feature (typically called "dynamic modulation") shall be provided in terms of a simple software upgrade without hardware replacement; this will allow saving large investments made in the last few years;
- next generation PDH / packet radios where the adaptive modulation concept will be extended in terms of modulation levels (up to 128/256) and management of the IP services released with future NodeB technology.

This paper speaks about the transient implementation of the adaptive modulation concept developed for existing PDH radios that represents the first network application foreseen for year 2007. The first implementation of such a feature was tested in laboratory on March 2006, and then on a field trial started on May 2006, in order to verify the proper system behaviour under typical propagation condition and rain fading. This paper provides the results obtained during this trial.

2. SYSTEM DESCRIPTION

Dynamic Modulation is an improving software functionality for already installed fixed point-to-point PDH microwave radio equipment, such that the modulation in use (4 QAM or 16 QAM) is automatically adapted to the propagation conditions of the communication channel (as depicted in Fig. 1), so that both link terminals always decode the received signal optimally. Though this evolved mechanism is not intended to accomplish a hit-less and error-free shift of modulation, only a short period of interruption occurs every time the system is re-arranged and since in most cases disturbances of less than one second have scarce influence on performance evaluation as well as on end-user's perception, the resulting service degradation can be considered acceptable.

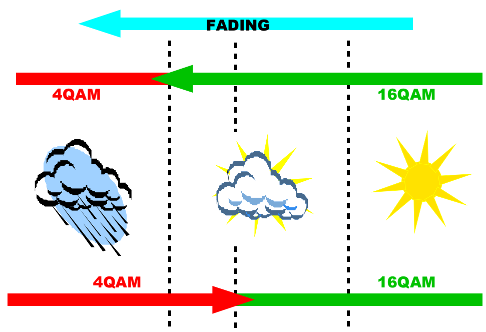


Fig. 1. Dynamic modulation concept

Laboratory tests, measuring the actual traffic interruption from the first to the last received error over a looped-back connection along the link, revealed that the complete re-configuration process lasts on average about 200 ms with only a small statistical deviation.

One of the main issues implementing the control algorithm was to develop a synchronization mechanism between link terminals without making hardware changes.

In order to detect a bi-directional fading occurrence, so that both terminals get ready to co-ordinately react to any further link degradation by rearranging their configurations, use is made of the existing ATPC signalling information, disregarding the possibility that the ATPC itself is actually not working.

Down-shifts are safely enabled just when each terminal already outputs its maximum power (as shown by the upper line of the 16 QAM curve in figure 2) while steadily exchanging messages, to and from the corresponding terminal, indicating the need to increase the signal level further, in order to compensate the perceived growing attenuation along the communication channel.

No other explicit messages are then required to make the terminals automatically re-configure themselves, since - either - both of them do it independently within a short time interval, according to the estimated bit error rate over the link connection – or – one of the two senses an abrupt change in the received signal (due to the remote re-configuration) and immediately interprets this as the need to down-shift the modulation.

Similarly, after having determined the fading regress by means of the ATPC signalling (when locally emitting the minimum transmit power and while receiving no requests from the remote terminal to increase it) and in absence for sufficient time of relevant alarm indications, one of the terminals (or both independently) prompts the other to restore the higher modulation as soon as also remotely the same conditions are met and lastly reacts to any abrupt change in the received signal by up-shifting the modulation.

Another interesting aspect of the proprietary implementation is the management of the transmit power. The adopted solution was envisaged since often - when using lower order modulations - the output power may be favorably increased to improve the overall availability performance, because the emitted spectrum is less affected by non-linear effects introduced by the radio transmitters.

Custom ATPC thresholds have been defined to be used at lower order modulation (along the 4 QAM lines marked with the arrows in figure 2). Hence, as the modulation shift takes place, the power is kept constant to smooth the transition, thus preserving (or at least making it more easily recoverable) the lock condition of the devices along the transmission chain; successively, the power is increased as much as foreseen by the ATPC settings, up to the new maximum allowable value (as indicated by the *power shift* label in figure 2).

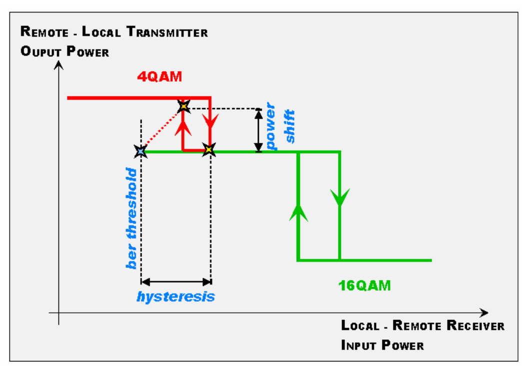


Fig. 2. ATPC behavior with dynamic modulation.

To limit the unavailability period of the extra traffic, it is also important that the comparing thresholds of the ATPC mechanism are not too far away from the field intensity value, which statistically determines the modulation down-shift; nonetheless a minimum distance is necessary in order to stabilize the adaptive modulation process, actually implementing a hysteresis protection, which avoids too frequent modulation switches when the received field fluctuates around an almost constant intensity. All the hysteresis parameters and time-out periods are software programmable, while some other working parameters had to be adjusted during the trial tests and have been made fixed.

In protected systems, in which transmitter and receiver parts are duplicated, more coordination among the units is needed to perform the modulation shifts efficiently and reliably. In particular, both incoming data streams in both directions must be near service degradation prior to down-shifting the modulation and – in the reverse case – the higher modulation can be restored only if good performance would be then likely provided by at least one receiver in both terminals.

Finally, to improve the process reliability in case of fault, every time the connection is lost for longer than a pre-determined time period, each equipment autonomously is made to switch to the lower modulation, while resorting to the maximum available transmit power.

3. TRIAL DESCRIPTION

The trial link has been deployed in the north eastern part of Italy, close to the urban area of Verona as depicted in Fig. 3. The main radio parameters of trial link are described in Table 1, where you can notice a difference of 12 dB in system gain between 4 QAM and 16 QAM modulation yielding very different outages due to rain fading

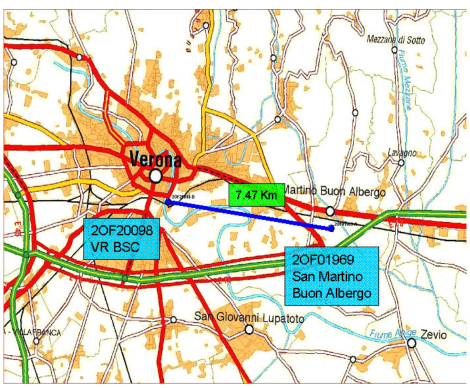


Fig. 3. Map of the trial location.

Table 1: Radio parameters of the trial link

Link description	4 QAM	16 QAM
Hop length [km]	7.47	
Frequency band [GHz]	23	
Antenna size [m] (*)	0.6	
Polarization	Horizontal	
Channel size [MHz]	14	
Radio capacity	8xE1	16xE1
Output power [dBm]	20	15
Prx @ BER 10-6 [dBm]	-83	-76
Link Margin [dB]	38	26
Outage [min/year]	42	110

(*) for both sites

The scope of trial measurements is to verify the correct modulation shifts (or switchover), called down-shift (from 16 QAM to 4 QAM) and up-shift (from 4 QAM to 16 QAM), according to propagation channel conditions and to system parameters settings that control modulation shifts described in section 2.

Trial architecture and measurement system are depicted in Fig.4, where the following can be noted.

- The radio link is hardware protected with 1+1 Hot Stand By technique, because we want to test the adaptive modulation behaviour together with 1+1 protection (more complex inter-working between dynamic modulation and hardware protection)
- Two PDH BER testers monitor high priority traffic (E1 circuits available both at 4 and 16 QAM) as well as low priority traffic (E1 circuits available only at 16 QAM)
- One PC directly connected to each radio terminal (IDU) in order to collect on site alarms, standard radio performance statistics (based on ¼ hour intervals) and specific received power and quality measurement (on a per second basis)
- Both PC's are connected to an IP network in order to monitor the system and to collect measurements from a remote site.

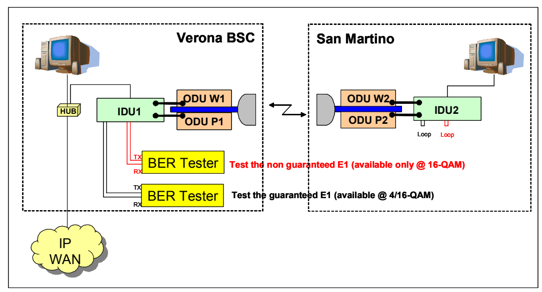


Fig. 4. Trial and measurement system architecture

4. TRIAL RESULTS

Eight full months of measurements have been recorded since the end of May 2006. The modulation switchover events during this trial period are listed in Table 2. It should be noted that although 7 events occurred during the whole trial period, only a few of them produced so deep fading to cause also 4 QAM outage.

Table 2: Main modulation switchover events

Day	Hour	16 QAM outage [sec]	Max rain fading [dB]
30/05/2006	9.13	183	30
30/05/2006	9.17	639	39
30/05/2006	9.29	934	47
01/08/2006	11.10	863	52
08/09/2006	22.12	331	37
08/09/2006	22.18	217	31
15/09/2006	6.20	70	29

During all the above listed events, the link was properly working and all modulation shifts occurred were stable and reliable. This is a first good result from trial, considering that this is one of the first realizations of this brand new feature implemented by software upgrade on existing hardware.

Besides, the aim of the trial was to better understand down-shift and up-shift triggering criteria (see chapter 2) and to test the equipment behaviour in a live scenario. From the operator point of view, this is the most interesting part because it allows determining the guidelines to define the best triggering criteria in order to:

- minimize the period when the link is operated at 4 QAM
- maintain a stable equipment behaviour during fading conditions (avoiding fluctuations among two modulations).

Separate analysis of down-shift and up-shift results are carried out in the following paragraphs.

4.1 Down-shift analysis

Down-shifts from 16 QAM to 4 QAM modulation occur during fading condition as soon as one of two receivers detects a BER higher than a given threshold. The threshold was set equal to 10^{-9} in order to maintain an error free link; ATM cells for UMTS applications are considered to be error free for BER less than 10^{-8}.

Down-shift events registered during the trial period have always produced only 1 or 2 ES (as recorded by BER tester), meaning that BER detection and down-shift together last less than 1 second as already proved by laboratory tests (about 200 ms).

Given the above mentioned BER settings for down-shift, and considering that 16 QAM guaranteed receiver sensitivity at BER = 10^{-9} is -75 dBm, it is expected that down-shift events occur only below this sensitivity threshold. Figure 5 shows one of the recorded events, where the relationships between received power, receiver threshold (-75 dBm) and modulation down-shifts can be seen.

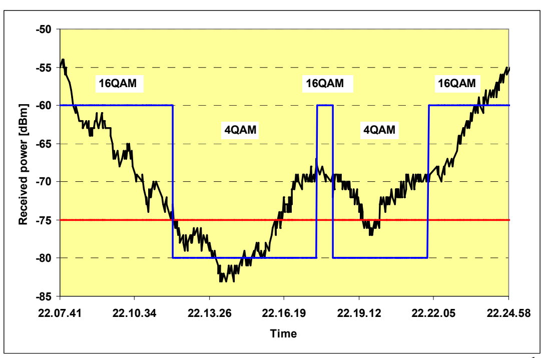


Fig. 5. Modulation switches occurred on 8th September 2006

The first down-shift (at 22.12) occurs exactly when the received power is -75 dB, while the second one (at 22.18) happens for a received power of about -70 dBm. This last down-shift is not correct and it has the effect to enlarge the period when the link is operated at 4 QAM; in this case it becomes about 1 minute longer.

During the trial we have registered some other down-shift events with a similar unexpected behaviour, beside those with a proper behaviour. After several analyses the problem was identified as deriving from a sometimes wrong BER estimation that generated modulation down shifts with a received power of about -70/-73 dBm. Therefore, a new BER estimation algorithm has been implemented and the latest measurements confirm the correct down shift behaviour. The switching towards more robust modulation scheme occurs now below -75 dBm.

4.2 Up-shift analysis

Up-shifts from 4 QAM to 16 QAM modulation occur when both ends of the link would receive a signal above the BER = 10^{-9} threshold (-75 dBm) plus a configurable hysteresis. This parameter was initially set to 5 dB, providing a power threshold for modulation up-shift equal to -70 dBm.

All up-shifts events recorded during this trial showed a behaviour according to this parameters (as depicted in Figure 5). Moreover, we never recorded an up-shift followed by an immediate down-shift after few seconds. This means that the hysteresis value is sufficient to avoid fluctuations among the two modulations.

Having recorded the received power with 1 dB resolution, we have also analyzed the hypothetical behaviour during up-shifts with different hysteresis values. This study was to evaluate the optimal hysteresis amount for the best trade-off between a prompt up-shift and avoiding fluctuations among modulations. The result is that with a hysteresis of 2 dB (threshold at -73 dBm) we can achieve a stable behaviour and a reduction of 16 QAM outage of about 25 % as shown in table 3. Following this kind of analysis the hysteresis parameter has been set at 2 dB. The trial link is still under measurement in order to verify the expected system improvement.

Table 3: 16 QAM outage; measured and optimal values

Day	Hour	Measured [sec]	Optimal [sec]
30/05/2006	9.13	183	104
30/05/2006	9.17	639	470
30/05/2006	9.29	934	704
01/08/2006	11.10	863	764
08/09/2006	22.12	331	249
08/09/2006	22.18	217	101
15/09/2006	6.20	70	50
Total		**3237**	**2442**

4.3 Overall performances

Also considering all the non optimal down-shift and up-shift behaviours described above, the recorded 16 QAM outage totals about 55 minutes in 8 months. If we compare this value with the design link outage (110 minutes/year), it is clear that trial link outage can be considered within design objectives.

In addition, considering to optimally set the up-shift hysteresis to 2 dB (instead of 5 dB, as explained previously in 4.2), the total 16 QAM outage will be reduced to 40 minutes in 8 months with a significant performance improvement.

Furthermore, considering a correct behaviour of down-shift mechanism for the entire trial period, the

total 16 QAM outage will be further reduced to 30 minutes.
This means that with proper system behaviour and optimal parameters settings, a link with dynamic modulation is capable to provide a 16 QAM outage according to link design availability objectives.

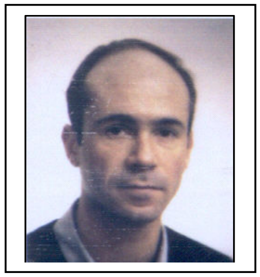
5. CONCLUSIONS

This paper describes an implementation of the brand new adaptive modulation concept developed for existing PDH radios, namely dynamic modulation, with a simple software upgrade of on field hardware.
Laboratory performances of such implementation (modulation shifts in about 200 ms) have been confirmed by a field trial. Link behaviour and modulation shifts were stable for the entire trial period and link reliability is the same of a static modulation link.
Trial results and analysis also allowed tuning parameters and algorithms that control modulation shifts among the two modulations in order to minimize 16 QAM outage periods. The resulting 16 QAM unavailability is within design objective.

BIOGRAPHY

Massimo Grimoldi received the Degree in Electronic Engineering in 1983 at "Politecnico di Milano".After a temporary assignement at Politecnico di Milano he joined Siae Microelettronica Spa in 1984. He was involved in the development of Base Band modules and Modems for digital radio equipments, becoming responsible for the Base Band laboratory in 1995; he is now Director of all SIAE's Digital Laboratories .

Gianni Marion received the Degree in Electronic Engineering in 1991 at "Politecnico di Milano".
He joined Siae Micro-elettronica Spa in 1992 and since then is part of the development team of PDH and SDH radio equipment.
He now leads the Base Band Digital Signal Processing Laboratory, responsible for developing error correction, synchronisation and criptography algorithms among others.



Paolo Agabio received the Degree in Electronic Engineering in 1995 at "Politecnico di Torino". He joined TILAB (the former CSELT) the research centre of Telecom Italia Group in 1997. He was involved in point-to-multipoint radio systems studies and trials. He actively participates to ETSI standardization groups for radio systems (TM4, BRAN Hiperaccess). Since 2000 he is in VODAFONE OMNITEL N.V., a private cellular operator, where he works on the development of the point-to-point and point to multi-point radio network for BTS backhauling of GSM and UMTS network. He is author or co-author of about 10 papers.
paolo.agabio@vodafone.com

Bruno Cornaglia received the Degree in Electronic Engineering at "Politecnico di Torino" in 1990. He joined CSELT, the research centre of Telecom Italia Group, in 1990. He was initially involved in millimetric radio relay links, both point-to-point and point-to-multipoint, and then in the introduction of Synchronous Digital Hierarchy (SDH). In 1994 he became Project Head of "Fixed Wireless Access" for studying and trialing new opportunities of using PMP networks for delivering basic services and new multimedia services. In the meantime he participated actively to various standardization bodies. In 1999 he joined OMNITEL Pronto Italia SpA, now VODAFONE OMNITEL NV, a private cellular operator, where he became responsible of "Point-MultiPoint Project" in 2000 for the deployment of a PMP network at 26 GHz in the major urban areas in order to backhaul 2G and 3G sites. In the meantime he also became the coordinator for BWA technologies in the Vodafone Group. In June 2005 he became responsible of New Product Development for Access Transmission under the Global Network organization of Vodafone Group. The main goals were to develop the right technology access transmission strategy and to drive the vendors to implement the right access transmission strategy. In August 2006 he became responsible of "Fixed Mobile Convergence" Team in the Transmission Group under the Global Network. The main responsibility is to develop a common strategy in the transmission area for delivering fixed mobile convergence services and to drive the operational companies to implement it. He is author or co-author of about 20 papers
bruno.cornaglia@vodafone.com

Stefano Veclani received the Degree in Electronic Engineering in 1997 at "Università degli Studi di Padova". He carried out a model of time-variant channel for the DAB system within "Padova Ricerche" (private company of local University). Since 1999 he has been in VODAFONE OMNITEL N.V., a private cellular operator, where he works as microwave engineer designing the PTP and PMP network in the North-East region. In June 2005 he joined the Global Network organization within Vodafone Group. The main goals are to develop and propose new technical solutions in the access transmission network driving the vendors towards Vodafone strategy.
stefano.veclani@vodafone.com