2xSTM-1 FREQUENCY REUSE SYSTEM WITH XPIC

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Abstract: Two split mount frequency reuse systems on an urban trial link in the 18 GHz band have been tested for about five months.
32 QAM and 128 QAM modulations have been used with and without Cross-Polar Interference Cancellers (XPIC). The XPIC systems are characterized by the possibility to expand an existing STM-1 radio to a 2xSTM-1 system without modifications to the existing outdoor equipment.
The results show that the XPIC is mandatory for 128 QAM, while for 32 QAM the cross-polar discrimination (XPD) of the employed antenna is the main dimensioning parameter. In the trial a high performance antenna was used, but nowadays antennas with a low environment impact, and consequently a reduced XPD, are preferred, forcing the use of XPIC also for the 32 QAM modulation.

Keywords: XPIC, SDH, nxSTM-1, split mount.

1. INTRODUCTION

During the last years the transmission capacity requirements by mobile operators in the BSS (Base Stations Subsystem) network (i.e. the network from the BSC to the BTS's and from RNC to NodeB's) have been increasing very fast:
capacity requirements increasing, but frequency resources being scarce, mainly in bands below 20 GHz, leads to the need of an increased spectrum efficiency of the transmission equipment.

One solution is represented by increasing the modulation level. However this solution is not always valid since it leads to a link margin reduction; increasing modulation level does worsen receiver sensitivity of the system. Moreover, with this solution a network upgrade will require a complete replacement of the microwave equipment, while operators prefer solutions with low impact on the existing network. For example, in a split mount system a modification of the outdoor unit is not considered acceptable.

For these reasons a system which is able to transmit both polarizations, vertical and horizontal, on the same radio channel is attractive from the operators point of view, especially if it will not require replacement of the existing outdoor units, even if a Cross-Polar Interference Canceller (XPIC) is needed: it provides to the reduction of the effect of the cross-interference created by depolarization over the hop, that will maintain more or less the same link margin.

2. SYSTEM DESCRIPTION

For a STM-1 traffic capacity the ETSI 55/56 or 27.5/28 MHz channel plans require typically 32 or 128 level modulations, that are very sensitive to interference: an adaptive XPIC is required to counteract the generated cross-polar interference and the XPD degradation, especially for 128 QAM.

In our case the XPD degradation is essentially due to rain, because short urban links (less than 10 km) are normally not affected by fast echo effects (multipath). This assumption allows us to adopt a solution that well achieves the requirement of minimum impact on a split mount radio system.

Fig. 1 shows a typical XPIC [1],[2],[3],[4], where the cross-connections at intermediate frequency (IF) are used for canceling the interference due to XPD degradation: the two outdoor units and the two XPIC modules are both connected together (dashed lines) for synchronization purpose.

Since for system upgrade is desirable not to modify the existing outdoor unit, the connection between the two outdoor units must be avoided. This constraint gives rise to the architecture reported in Fig. 2 and used in the trials, where the outdoor units are fully independent and the IF connections for the XPIC inputs are easily implemented in the indoor part. For synchronization purpose a second carrier recovery loop is implemented in the XPIC subsystem (patented), which eliminates the connections between the two outdoor units.

The trial with 32 QAM has been implemented in two steps, where the first one uses a simple correlation in the XPIC carrier recovery. While the traditional XPIC system described in Fig. 1 recovers from a degraded condition with only a few dB of hysteresis in the wanted/interfering ratio (W/I), the simple algorithm applied in the trial system shown in Fig. 2 needs a W/I improvement of 10 to 12 dB. In fact, the system restarts only when both carrier recovery loops, one of demodulator and one of XPIC, are jointly in lock. Their mutual dependence produce an enlargement in the hysteresis, compared to the traditional solution where only a single loop is needed.

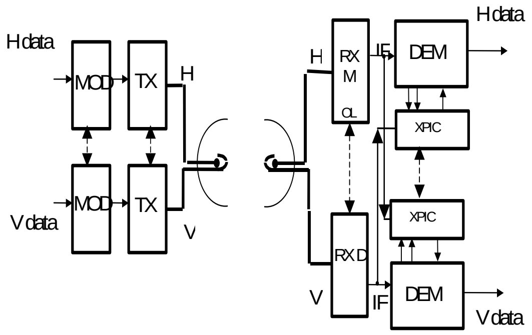

Fig. 1: Typical XPIC architecture.

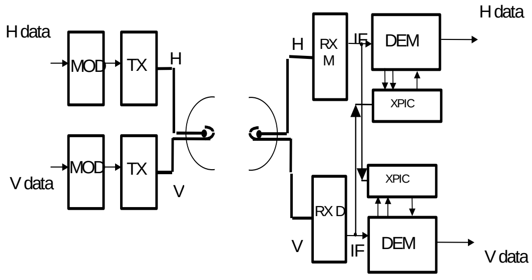

Fig. 2: XPIC architecture employed in the trials.

The impact of such an histeresys enlargement is included in the objective of the trial links. Rain has typically a rise and fall time faster than the rainfall duration that produces the effective outage, so the hysteresis effect during transitory cannot produce relevant variation on the final total outage.

The multipath case, on the other side, is characterized by a frequent jumping between sync-loss condition and degraded only condition, involving the recovery capability. It is therefore reasonable to think that, for multipath, the architecture of Fig. 1 might be more suitable than the one of Fig. 2 with the simple algorithm, but we are not aware of measurements to support the assumption.

To safeguard also the multipath situation with the solution of Fig. 2, a more advanced algorithm (patented) has been developed, characterized by an hysteresis of 4 dB. This is a very good result, that can be considered suitable also for long-haul hops, giving a high performance - minimum impact system.

The trial on 32 QAM link used the first, simple algorithm, while in 128 QAM trial a better advanced algorithm was adopted. In this case, with an error rate of $2 \cdot 10^{-7}$ due to thermal noise, a W/I ratio of 5 dB causes a carrier loss and the recovery is achieved with a W/I ratio in the range of 11 to 15 dB. Nowadays, this solution has been further enhanced, producing even better performances, whose effects only a long-haul trial would better highlight.
It should be noted that it is generally difficult to try to investigate in detail the joint effect of interference and canceller. In fact W/I values should be known with off-line measurements and the signals should be processed with and without cancellers. Outage due to interference is usually a small portion of the global outage and it can be masked by the thermal noise and/or spectrum distortion. However, during these trials some events have been found, that can help operators to understand the behavior of the system during rain conditions and to verify the parameters used in the planning process.

3. TRIAL DESCRIPTION

The trial links have been deployed in the north west part of the urban area of Milan (Italy) as depicted in Fig. 3. The two links have a common site (B) in order to have a single point for collecting measurements.

The main radio parameters of the two trial links are described in Table 1.

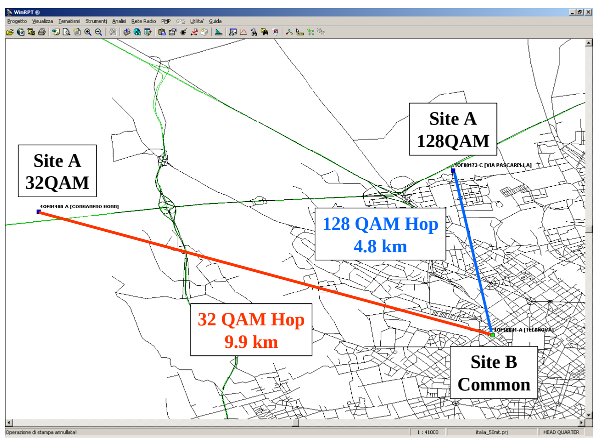

Fig. 3: Map of the trial locations and hops.

Table 1: Radio parameters of the 2002 trial links.

Parameter	32 QAM	128 QAM
Hop length [km]	9.9	4.8
Site A antenna diam. [m]	0.6	0.6
Site A antenna XPD [dB]	35	30
Site B antenna diam. [m]	1.2	0.6
Site B antenna XPD [dB]	31	30
Site A TX freq. [GHz]	18.085	18.140
Site B TX freq. [GHz]	19.095	19.150
Azimut from North [deg]	291	350
Prx @ BER 10^{-3} [dBm]	-75.4	-71
Link Margin [dB]	36	30
W/I @ 1 dB degradation BER 10^{-6} [dB]	27	34
W/I @ BER 10^{-6} [dB]	20	28
Measured XPD [dB]	31	27
XPIC improvement [dB]	17 - 23 (Phase dep.)	20 - 25 (Phase dep.)
With XPIC, 1 dB BER 10-6 degradation for W/I	4 – 10	9 - 14

It must be remarked that during this trial (year 2002) dual beam antennas were used: this fact places the system in the worst XPIF when measured in windy clean air steady state conditions. Nowadays the dual polarized antennas are usually manufactured using an orthomode transducer (OMT): it is well known that this technique would allow the system, for the same conditions, to obtain best XPIF performances.

Considering the behavior of the receivers without XPIC (C/I ratio for 1 dB degradation BER 10^{-6}) and the C/I measured on field in clear sky conditions (Measured XPD) the following general considerations apply for the trial links:

- The 32 QAM system works with a margin of about 4 dB, which means that a system without XPIC can operate without errors as long as propagation conditions do not produce signal depolarization.
- The 128 QAM system works at about 7 dB below the C/I threshold, which means that even in clear sky conditions a system without XPIC would not operate without errors.

The architecture of the measurement system, for both the 32 QAM and the 128 QAM hops, is depicted in Fig. 4.

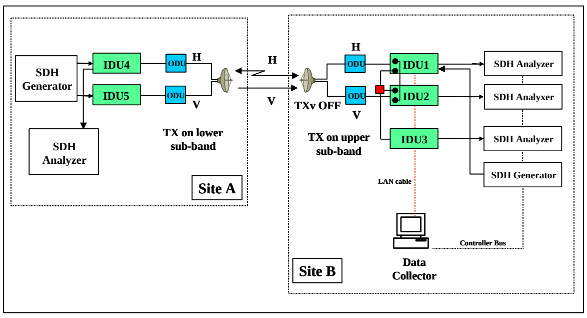

Fig. 4: Measurement system architecture.

The architecture depicted in Fig. 4 highlights the following facts.

- The frequency is reused (H and V polarization) from the sites A to site B, while in the opposite direction the V transmitter is switched off.
- On site B 32 QAM section there are 3 modems, two operates with XPIC while the third one receives the signal on H polarization without XPIC.

This architecture allows to compare the behavior of the link without frequency reuse (IDU 4), the link with frequency reuse with XPIC (IDU 1 and 2 for H and V polarization) and without XPIC on H polarization (IDU 3).

Since site A receives on the higher frequency sub-band (1 GHz above site B), it is more attenuated by rain. Therefore, it cannot be taken as an absolute reference, but can be considered an upper limit for the XPIC system performances.

For the 128 QAM system there are no significant results on the frequency reuse link without XPIC (IDU 3) because the XPD in clear sky conditions gives a constant high BER alarm (as expected from the planning).

4. TRIAL RESULTS

By the end of September 2002, 19 weeks of measurements have been recorded for the 32 QAM link, while the measurements on the 128 QAM link cover 10 weeks. In Table 2 is reported the list of the main rain events during the trial period for both links, with the relevant maximum rain fading recorded: there are 35 events during the summer, some of them with very high fading, that have produced a significant amount of data.

Table 2: Main rain shower events.

Day	# of events 32 & 128	Max. rain fading [dB] 32 QAM	128 QAM]
05/03/02	5	40	
05/23/02	1	40	
05/25/02	1	30	
05/27/02	1	20	
06/05/02	1	40	
06/08/02	1	20	
06/08/02	1	35	
06/28/02	3	25 -40	
07/03/02	2	20	
07/06/02	1	40	
07/31/02	1	35	15
08/03/02	1	40	15
08/04/02	1	40	20
08/05/02	1	25	25
08/20/02	1	40	15
08/21/02	1	40	15
08/23/02	2	40	15
08/25/02	1	40	30
09/03/02	2 1	30	12
09/09/02	1 2	39	13
09/13/02	1 2	11	22
09/21/02	3 1	37	40
09/22/02	1	37	40

The main objective of the trial is to examine the impact of the XPIC on the hop availability and its need for satisfactory link operation.

In fact, XPD degrades in presence of attenuation due to the rain, but the same value of attenuation in different periods doesn't produce the same XPD degradation, because rain and wind combination can produce several physical characteristics of the transmission channel. This fact is easily shown in the recorded data. Furthermore, the periods of deep attenuation, below the threshold, have not been considered in the evaluation, because both demodulators (with and without XPIC) produce errors due to noise floor.

So, the cases of interest remain those with attenuation a few dBs above the threshold. Rise and fall intervals of the rain phenomena would also be interesting, but they usually occupy a small or very small portion of the total attenuation period, as data show.

The paragraphs below provide the results and their relevant analysis for the 32 QAM and 128 QAM links.

4.1 32 QAM link results and analysis.

The data collected on the 32 QAM link are summarized in Table 3, in terms of number of errored seconds over the entire measurement period (19 weeks).

Table 3: Total number of errored seconds.

Link description	Errored seconds
POL V, 18G, freq.reuse with XPIC (IDU 2)	3369
POL H 19G, without freq. reuse (IDU 4)	5133
POL H, 18G freq. reuse with XPIC (IDU 1)	4086
POL H, 18G freq. reuse NO XPIC (IDU 3)	4213

The events of sept./21 and 22 have not been included due to lost records for the modem without XPIC.

Table 4: number of errored seconds on selected days

Link description	day	Errored seconds
POL V 18 G, freq. Reuse with XPIC (IDU2)	09/21/02	1289
POL V 18 G, freq. Reuse with XPIC (IDU2)	09/22/02	lost
POL H, 18G freq. reuse with XPIC (IDU 1)	09/21/02	1404
POL H, 18G freq. reuse with XPIC (IDU 1)	09/22/02	520
POL H 19G, without freq. reuse (IDU 4)	09/21/02	1599
POL H 19G, without freq. reuse (IDU 4)	09/22/02	622

Tables 3 and 4 show the following expected results:

- the link on V pol with frequency reuse had the lowest number of errors (because of intrinsic robustness of this polarization).
- the link on H pol without frequency reuse had the maximum number of errors because it operates at 1 GHz higher frequency.
- the links on H pol (with or without XPIC) have very similar values.

Therefore, it is interesting to analyze in details the behavior of the links on horizontal polarization with and without XPIC. Table 5 summarizes the number of errored seconds event by event.

Table 5: Errored seconds for each rain event.

Date of event	Modem XPIC Errored seconds	Modem without XPIC Errored seconds
3th may	522	519
3th may	744	742
3th may	129	139
23th may	1078	1100
5th june	301	291
6th july	251	293
31th july	57	68
3th august	485	471
4th august	369	412
9th september	150	178

The table shows a very similar behavior, where sometimes the modem with XPIC experience better results and sometimes not. Therefore, a conclusion does not appear immediate and further investigations event by event are useful.
In the following figures are depicted the recorded (with a one second time basis) values of:

- received power (Prx); the recording is limited at a value of –79 dBm and the step of variation is of 2 to 3 dB
- the alarm level values which correspond to error free (0), early warning (level 1, BER $=10^{-9}$), low BER (level 2, BER $=10^{-6}$) and high BER (level 3, BER $=10^{-3}$).

Fig. 5 shows the results recorded during the events on 23rd of May, where the modem with XPIC provided better performances than the modem without XPIC. This figure clearly shows that the different performances of the modems occur during rise and fall periods of rain fading. This means that during this event the XPIC modem has cancelled harmful interference due to depolarization, producing about 22 errored seconds less than modem without XPIC.

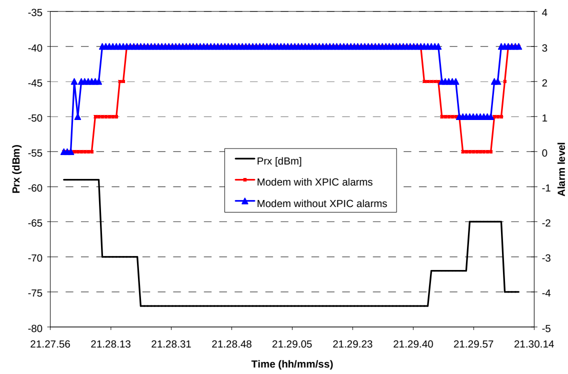

Fig. 5: Received power and alarm levels during rain fading event on 23rd of May.

As listed in table 5, there are events where the modem with XPIC provided worse performances than the modem without XPIC. This means that during this rain fading there was not a strong depolarization. The additional errored seconds recorded on the XPIC

modem can be attributed to slight differences on the two receivers and the intrinsic slightly higher noise floor of a receiver employing a linear XPIC algorithm.
Nevertheless, even if 32 QAM is intrinsically robust against interference, also on short urban links cross polar canceller is needed. Sometimes rain can have a rapidly change, giving an attenuation around receiver threshold as well as XPD degradation as depicted in figure 6. This figure shows also the W/I (carrier to interference ratio) estimation provided by equipment in addition to receive power and BER alarms. This figure points out the following:

- there are short periods when depolarization yields a W/I < 16 dB that is critical for a 32 QAM link without canceller
- the result is an additional 14 seconds period of errored link (HBER) for the receiver without canceller; and in general longer periods of BER alarms without interference canceller.

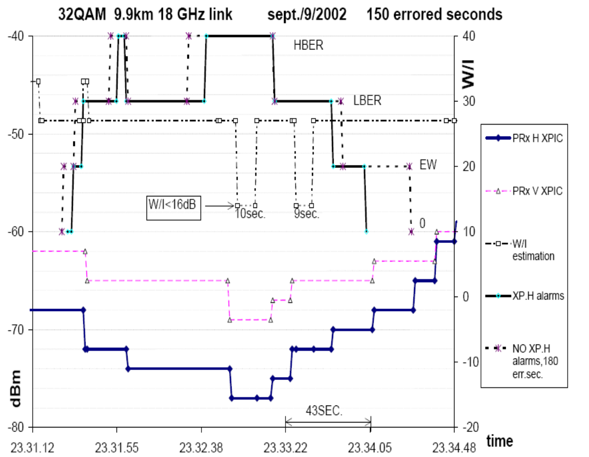

Fig. 6: Parameters of 9th September.

Figure 7 depicts a similar event of critical XPD degradation (W/I < 16 dB) that lasts for a longer period of about 3 minutes. The impact on overall outage performances is not that big (3 minutes) because for a great part of this period also the received power is below receiver sensitivity.

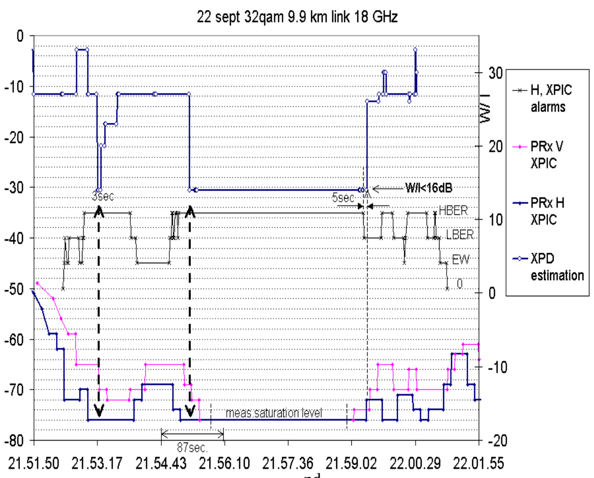

Fig. 7 : Parameters of 22nd September event.

All the events described seem to well represent the reason why the long period measurement is characterized by a not very significant difference in the overall performance (4035-3936 = 99 sec) between modems with and without XPIC. This can be explained considering the evaluation (according to Rec. ITU-R P.530-9) of the carrier to interference ratio (C/I is the same as W/I) on the trial link, for different percentage of time (rain fading) and for different rainfall inclination (angle α). This is very important, because it is the combination of rain attenuation and rain inclination over the link that can produce depolarization (XPD). In Fig. 8 the C/I ratio is shown together with the following.

- The percentage of time corresponding to link outage (due to link margin); this means that below this value the outage is due to noise.
- The C/I threshold (BER=10^{-6}) of the receiver without XPIC: this means that under this value the link without XPIC generates errors.

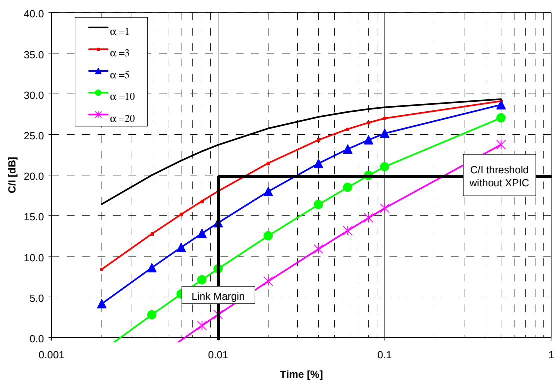

Fig. 8: C/I ratio for different rain fading and rainfall inclination (α).

The plot in Fig. 8 has to be interpreted as follows: a different behavior between the two modems could happen only below the C/I threshold and above the link margin (that is, in the lower right part of the diagram). For this link it means that cross polar canceller operates for significant period of time only during deep fade condition and for rainfall inclination above 10 degrees.

4.1 128 QAM link results and analysis.

The 128 QAM is implemented with a different hop length and configuration: even if the 32 QAM link (9.9 km) could have an higher rain statistic, the 128 QAM link (4.8 km) also shows an interesting behavior. The data collected on the 128 QAM link are summarized in Table 6, in terms of number of errored seconds.
Apart the intrinsic robustness of the vertical polarization, Table 6 shows similar results between the two H-pol modems (frequency reuse and XPIC / without frequency reuse). The comparison is quite reasonable because on this link the attenuation difference between the sub-bands (1 GHz duplex spacing) is not very large (about 2-3 dB).

Table 6: Total number of errored seconds.

Link description	day	Errored seconds
POL H 19 GHz not reused (IDU 4)	08/25/02	414
POL H 18 GHz reuse & XPIC (IDU 1)	08/25/02	330
POL V 18 GHz reuse & XPIC (IDU 2)	08/25/02	0
POL H 19 GHz not reused (IDU 4)	09/21/02	207
POL H 18 GHz reuse & XPIC (IDU 1)	09/21/02	163
POL V 18 GHz reuse & XPIC (IDU 2)	09/21/02	100
POL H 19 GHz not reused (IDU 4)	09/22/02	873
POL H 18 GHz reuse & XPIC (IDU 1)	09/22/02	791
POL V 18 GHz reuse & XPIC (IDU 2)	09/22/02	427

This fact can also be analyzed considering the plots in Fig. 8, which shows the received power and the alarm levels regarding these two modems. This figure shows very similar behaviors, with long periods of alarm indicating BER above 10^{-6}, mainly due to weak received field strength, disregarding the reuse of the same frequency on the opposite polarization.

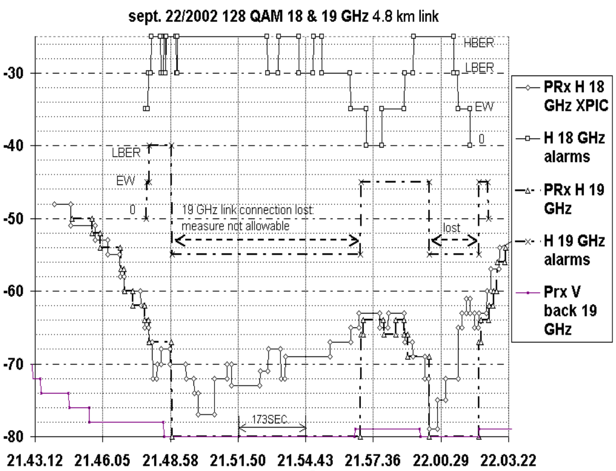

Fig. 8: Received power and alarm levels during rain fading event on 22nd of September.

Moreover, on this 4.8 km link more often than on the 9.9 km link an attenuation has been measured, during deep phenomena, on 18 GHz similar to 19 GHz.

Fig. 9 shows the C/I ratio over the 128 QAM link evaluated in the same way as described in fig.8 for the 32 QAM link.

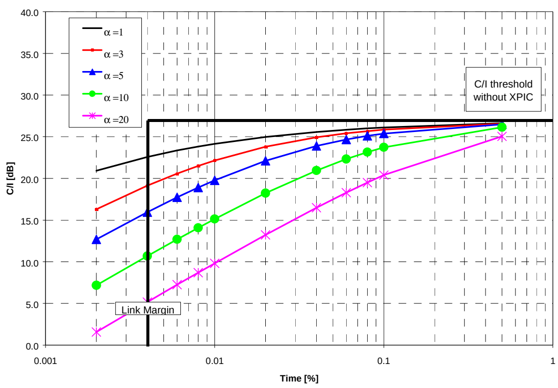

Fig. 9: C/I ratio for different rain fading and rainfall inclination (α).

Fig. 9 shows that the XPIC is mandatory for this link (C/I always under the threshold), due to low XPD antenna performances as described in chapter 3 and experienced during field trial. Considering that during the events reported on table 6 the link was very close to link margin, it is straightforward that the XPIC algorithm has been stressed with C/I ratio down to 20-10 dB (depending on rainfall inclination). The result is that, during this event, the link with frequency reuse provided the same performances as the link without frequency reuse.

5. CONCLUSIONS

New XPIC algorithms have been tested with carrier recovery loops inside XPIC modules. These new algorithms allow to avoid the cross-connection of the two outdoor units, thus significantly simplifying link upgrade from 1xSTM-1 to 2xSTM-1.

The 128 QAM trial uses standard XPD antennas, that make XPIC mandatory also during clear sky conditions. The period of this trial covers about the whole spring to summer stormy season and the employed XPIC algorithm seems to provide the expected performances.

The 32 QAM trial uses high XPD antennas, that allow the link to work well without XPIC. However, during rain fading the XPD is influenced by the combination of wind (rainfall inclination) and rain intensity. Due to the uncertainty of the occurrence of these conditions also on urban short links, we do consider necessary the use of XPIC also on 32 QAM radio systems. Moreover, nowadays new equipment generations are normally configurable for a wide set of modulation levels (32/128 QAM) and the XPIC feature, mandatory for 128 QAM, is also available for 32 QAM.

Following 2002 trials described in this paper, Vodafone Omnitel started to implement SDH hops in 11 GHz and 18 GHz bands with XPIC all across Italy. During last 4 years all these links have provided expected results, without a single unexpected outage due to interference.

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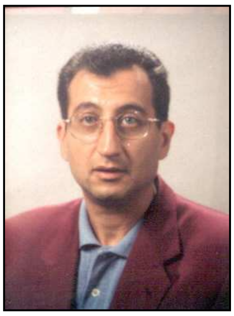
BIOGRAPHY



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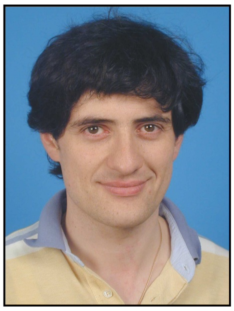

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