LoS MIMO in Full Outdoor Microwave Radio

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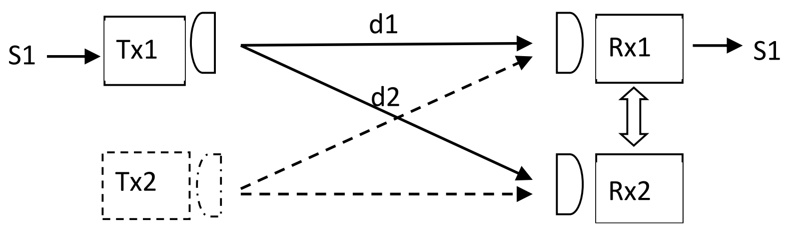
Microwave Radio upgrade in fixed capacity scenarios (TDM)

Starting from a basic 1+0 unprotected system, frequently adopted in mobile network tails with low capacity traffic, the "first level" upgrade is historically represented by the **Hot-Stand-By (1+1)** configuration: in this case, the 1+0 link is protected against failure by a second transceiver that is normally powered on but with the transmit signal switched off. In case of failure of the main link, the protecting one is able to operate in less than one second, typically. Two transceivers per site are necessary with two antennas, or more commonly with one single antenna connected through a passive hybrid, balanced or unbalanced. This last case allows for a low system gain loss when the main RT is in operation, requiring a "revertive" behavior after failure removing.

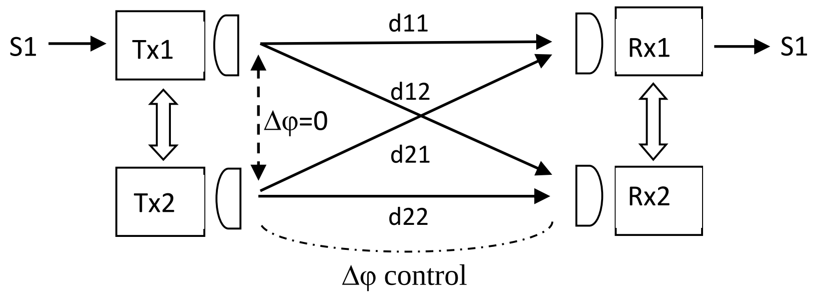
A different kind of protection, largely adopted in the past, is obtained by the Space Diversity configuration, when we have a single transmitter and two receivers, operating in parallel on the same transmitted signal. The two demodulated data streams, exploiting in this case the spatial uncorrelation (antennas distance should be in the order of the RF signal wavelength, in practical cases several meters), are combined "in-phase", so that optimizing the RX C/N.



Space Diversity has been proven very effective in case of multipath fading (low frequency bands). In case of high frequency bands, where rain attenuation is predominant affecting equally the two paths, the only advantage of this configuration is the 3 dB increase in system gain, due to the in-phase combination of the two received signals.

In case of full ODU transceivers, a second transmitter is always anyhow available, so that this SD configuration can also perform as Hot Stand-by protection in case of failure on the main transmitter, so that representing a "second level" upgrade: let's call it **SD (1+1).**

A further upgrade, again at the same "per link" equipment cost of the Hot Stand-by configuration, can be obtained transmitting and receiving the same data stream on two antennas spatially uncorrelated. In this configuration the two transmitters are both active and, as in the previous case, at the receive side an in-phase combiner makes available a replica of the transmitted data.



This "third level" upgrade, let's call it **Extended SD (1+1)**, in addition to the protection against selective fading (multipath) on the channel, can give a system gain increase of up to 9 dB, allowing for an extended hop length. To achieve this system gain increase it is necessary to keep the TX signals in phase with high accuracy. This can be obtained by implementing a remote loop-back channel on the link, that could also be useful for other purposes (e.g. adaptive digital pre-distorsion).A failure protection is also available in this configuration, only loosing the extra system gain until failure is removed, that means for a short period of time, unlikely happening during fading conditions.

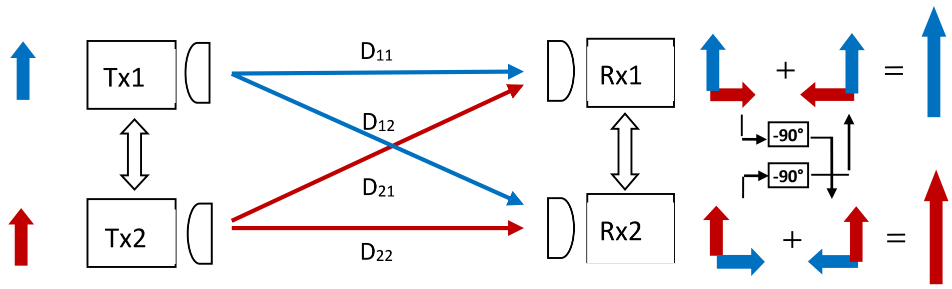
System upgrade in the new variable capacity scenario (IP Radio) : from SISO to MIMO

Starting from a standard Single Input Single Output (SISO) protected configuration, based on two complete transmitters and two complete receivers (two full ODU's) and considering an IP transport based on different classes of service, a cost effective system evolution is obtained by doubling the maximum link capacity on the very same radio channel, adopting a Multiple Input Multiple Output (MIMO) arrangement. To achieve this goal, it is necessary to guarantee a sufficient uncorrelation of the received RF signals. In case of failure or severe multipath conditions, the link will act as a protected one, losing part of the traffic, down to the limit of a single transmitter capacity (e.g. maintaining the higher quality class of traffic), exploiting ACM as well.

- **Line-of-sight MIMO Concept**

MIMO is a well-known technology for increasing spectral efficiency in WiFi and RANs. An NxN MIMO system comprises N transmitters and N receivers with the potential to simultaneously transmit N independent signals, so that multiplying by N the link capacity. The basic principle of MIMO is that a signal will use different paths between transmitters and receivers. In a 2×2 MIMO system, there are two possible paths between one transmitter and two receivers. In conventional nLOS MIMO systems (namely 2 to 5 GHz WLAN links), the difference in path is achieved through multipath propagation.

For microwave links, it is not possible to take advantage of multipath because these links are operated in line-of-sight mode with highly directional antennas, so in this case LOS MIMO is considered.



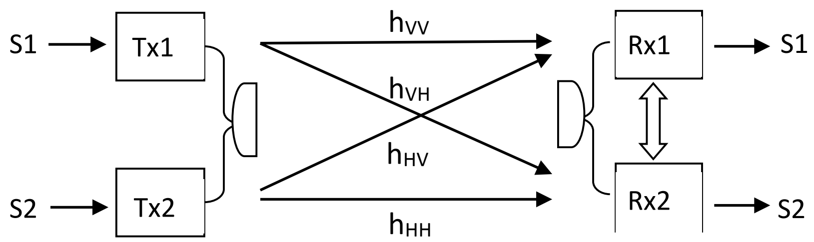
MIMO (2,2) with $\Delta_{path} = \lambda/4$

The interfering signal can be cancelled, while maximizing the wanted signal, if the difference in propagation between the two paths brings to have orthogonal received signals at the receives rinput. A geometric calculation can be done to obtain the optimum antenna separation, D_{12}-D_{11}= $\lambda/4$:

$$(d_A)^2 = Dc/2f$$

Where $\mathbf{d_A}$ is the antenna separation, **D** is the hop length, **c** is the speed of light and **f** is the radio frequancy with relevant wavelenght **λ.**

- **MIMO (2,2) Dual Pol (XPIC)**



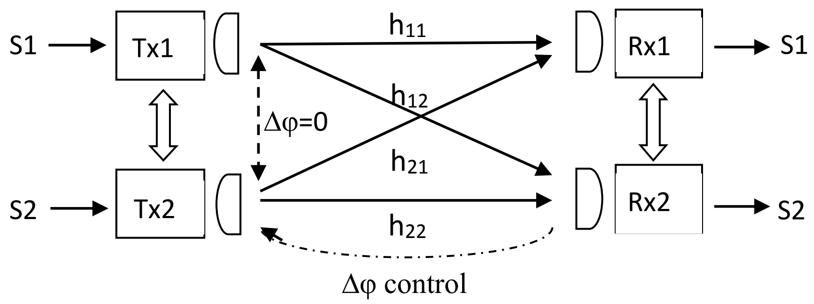
In this configuration, the considered link is obtained with two transmitters and two receivers operating in parallel. Two TX data streams, independent or obtained through a dedicated load balancing technique from one single main stream, feed the two transmitters both connected to a single dual-polarized antenna.

At receive side, a cross-polar interference canceller (XPIC) allows for the reconstruction of the transmitted data streams.

In addition to the doubling of capacity on the same radio channel achieved by this way, a radio link protection can also be obtained (halving the total capacity of the link) in case of failure on V or H channel, or in case of bad propagation conditions. In fact, when adopted, this configuration can substitute a Hot-Stand-By standard configuration at the same implementation cost, while granting a capacity doubling on the same channel bandwidth.

This type of MIMO (2,2) takes advantage from the intrinsic dual pol antenna XPOL decoupling,

- **MIMO (2,2) Single Pol**



This case is similar to the previous one, but here the two transmitted radio signals are uncorrelated due to different physical paths (space/time de-correlation), having two separated antennas for transmission and reception. At the receive side the Combiner/Canceller acts maximizing the wanted signal and minimizing the interfering one. The two TX (and RX) antennas have to be spatially separated so that the two received signals enter the same antenna with a phase difference of 90° (orthogonal). Such an optimum decoupling is guaranteed when d_{12}-d_{11}= $\lambda/4$ (an additional System Gain of 3 dB is also available in this case), but in practical cases of RF frequencies in the range 15 to 38 GHz the resulting antenna separation becomes problematic for practical installations. A good trade-off is reached dimensioning d_{12}-d_{11}= $\lambda/8$ (no System Gain advantage).

The following examples are related to this last arrangement:

D=5 km, f=23 GHz ⇨ $d_A \approx$ 3 m

D=2 km, f=38 GHz ⇨ $d_A \approx$ 2.8 m

D=1 km, f=80 GHz ⇨ $d_A \approx$ 1.4 m

- **MIMO (4,4) Dual Pol**

Extension of the previous case, of practical interest when added to an already implemented XPIC solution, to realize a four times capacity on the same channel bandwidth.

One MIMO (4,4) solution with at maximum 256QAM, representing the upper limit of present technology, brings an advantage of up to 60% in capacity, with respect to the “simple” MIMO (2,2) XPIC at 1024QAM. This solution appears of extreme interest in the most largely adopted channel separation of 28 MHz, allowing for a gross bit rate of about 800 Mbit/s (GEth connection almost fully exploited).

This solution is offered with a complete installation expandability: from one single unprotected ODU, to an XPIC (1+1 protected) by adding a second ODU connected to the same DP antenna and finally adding two more XPIC ODUs and two more antennas, to obtain a DP MIMO (4,4).

It is by consequence of primary importance to adopt a smart “chain” interconnection among the different ODUs, to carry the high speed data streams needed for interference cancellation and load balancing of the main traffic.

The single ODU are equipped with suitable high speed interfaces, for input/output data from/to the network, for load balancing among the different ODUs and for XPIC and MIMO cancellation signals.

Comparison

In the following table the main characteristics of the most significant system upgrades, associated to a general +/- evaluation, are summarized,

	HSB (1+1)	**Ext SD (1+1)**	**XPIC (2,2)**	**MIMO (4,4)**
Protection	Failure	Fail/propag	Fail/propag (2C→C)	Fail/propag (4C→2C→C)
Max Cap /ChS	C	C	2C	4C
Δ SG	-1÷-2 dB	9 dB	0	3 dB
Overall Performance	-	**++** (L_{HOP})	**++** (Capacity)	**+++** (L_{HOP}/Cap)

Conclusions

From the previous analysis it comes out that, in addition to the basic 1+0 system configuration, in case of link protection against failure, an XPIC solution has to be largely preferred with respect to the “classic” Hot-stand-by 1+1 protection. In fact, at a comparable product cost (two SP antennas vs one DP antenna plus one orthomode coupler), a double capacity (at same System Gain) can be transmitted on the link in nominal conditions.

In case of system protection against Multipath (Space Diversity), the SD (2,2) solution is preferable, compared to the “classic” SD (1,2), offering (again at comparable product cost) a considerable higher system gain, in addition to a TX failure protection.

The “ultimate” spectral efficiency, achievable with today technology, can be reached with a MIMO (4,4) DP configuration. In this case, assuming 256 QAM as maximum modulation format (three residual interfering signals on the same radio channel representing the limiting factor for this upper limit complexity), a 32 bit/s/Hz specrum efficiency is obtained, more than three times the efficiency of a standard (SISO) link operating at 1024 QAM. By this way, a total gross capacity of nearly 1 Gbps can be carried on a 28 MHz (ETSI) or 30 MHz (ANSI) single radio channel.