White Paper

Building Better Microwave Trunk Networks

DragonWave

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INTRODUCTION

This document provides an overview of the highlights and applications of trunk microwave radio point-to-point telecom equipment. The content of this whitepaper is mainly based upon the features and roadmap of the Harmony Trunk product from DragonWave, but is applicable in general to any microwave trunk equipment as a concept.

TRUNK APPLICATIONS AND ACCESS APPLICATIONS

MW Trunk and MW Access systems complement each other in backhaul networks

The first point addressed by this paper is the trunk MW radio positioning: let's clarify the main differentiators of trunk MW systems compared to access MW systems. Trunk MW systems are generally tailored to wireless telecoms applications where very high capacity traffic requiring multi-carrier RF spectrum and long haul coverage is requested. It means that trunk MW systems are mainly useful in digital transport backbones (national, regional or sub-regional level), in conjunction with or as an alternative to fibre optics telecom networks. They are also useful in high order aggregation layers of the backhaul network, as soon as the groomed capacity becomes too high to be transported by a single RF carrier (which is the typical capability of access MW systems), and multi-carrier RF spectrum use (and eventually long haul coverage as well) is instead needed to provide suitable and reliable communication.

THE MULTI-CARRIER PARADIGM

Multi-carrier transport allows larger hop coverage and improved data resiliency

In this first glance positioning of trunk MW systems it shall be underlined the linkage between the high capacity and the long haul coverage mentioned above: these two parameters (high capacity, long haul) are inversely correlated, and the trade-off between these two parameters is solved in trunk MW systems by the paradigm of multi-carrier RF spectrum usage, which is the real differentiator with respect to access MW systems. In other words, while it is clear that even with access MW equipment nowadays it is possible to achieve very high capacity with just a single RF carrier (very high modulation up to 1024QAM, 2048QAM, 4096QAM, very wide bandwidth up to 56MHz, 80MHz, 112MHz single carrier), the more the capacity increases in a single carrier, the more noise significantly affects the propagation, thus worsening the RX threshold of the system, thus reducing the maximum length coverage pertaining to certain performance and availability targets. It is of course true that adaptive modulation (if hitless and QoS-driven) removes any doubt about RX threshold degradation issue caused by the higher order modulation formats (because RX threshold is worsened just for the extra capacity added by the higher order modulation formats, whilst it is improved instead for the very high priority basic traffic which remains still on air even in presence of deep fading triggering lower modulation formats, see next paragraph as well), however here the point is:

- When there is some propagation impairment affecting just a portion of the spectrum (like a multipath fading), the use of a single carrier would imply that all the spectrum is affected by capacity reduction,
- Similarly, when a HW failure occurs on a single carrier system, it impacts the

full capacity transported by the complete system.

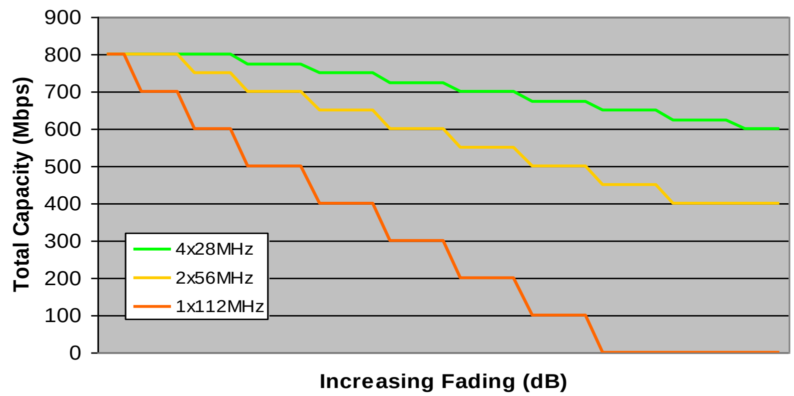
On the other side, if the same bundle capacity is transported by using Nx RF carriers instead of a single carrier, any multipath fading or HW failure would affect just the portion of the spectrum where it falls, while the rest of (N-1)x RF carriers would continue to run at full speed. It means better use of spectrum and reliability of trunk MW systems than access MW systems, even in case the total bundle capacity is same.

An example of Harmony Trunk multi-carrier operation vs single-carrier

Example

Let's consider one Harmony Trunk system in 4+0 configuration and full-IP transport over a channel arrangement with 28MHz spacing (4 RF carriers of 28MHz bandwidth with adaptive load sharing). Such system can use adaptive modulation up to 512QAM, thus transporting up to 800Mbps (4x200Mbps) during normal operation (ref. green line in diagram below). Let's assume that a multipath fading happens on one carrier, causing RSL to decrease down to 512QAM RX threshold: modulation on that carrier switches to 256QAM, thus reducing the total capacity of the aggregated bundle to 775Mbps (3x200Mbps + 175Mbps), meaning 3% traffic reduction. In case fading becomes so strong to prevent any possibility to transmit traffic on that carrier (or in case of HW failure on one carrier), the capacity comes down to 600Mbps (3x200Mbps), meaning 25% traffic reduction. Now let's consider same circumstances in case of a single carrier system carrying same total traffic, i.e. 800Mbps: such a system should have 112MHz bandwidth and modulation up to 512QAM (ref. orange line in diagram below). Of course this system has got a very bad RX threshold with respect of multi-carrier, because of larger bandwidth (at least 6dB worse RX threshold and possibly even worse TX power, meaning system gain 6-9 dB lower than the Harmony Trunk of the example above), thus meaning that the same fading causing 512QAM to 256QAM in Harmony Trunk 4+0, this time would cause switch up to 64QAM format in best case thus causing rate reduction down to 500Mbps (same as 4x125Mbps), meaning 37% traffic reduction instead of the 3% reduction calculated for Harmony Trunk for same fading. And in case of very deep fading (or HW failure) the capacity would decrease to zero, meaning 100% traffic reduction against the 25% calculated for Harmony Trunk. Even in case we consider not a single carrier 112MHz, but two carriers 56MHz with load balancing, the situation is not so much better: 12.5% traffic reduction in case of light fading vs the 3% of Harmony Trunk, and 50% traffic reduction in case of deep fading (or HW failure) vs the 25% of Harmony Trunk (ref. yellow line in diagram below).Looking at the diagram below we can achieve following conclusions:

- Multi-carrier systems maintain the maximum bundle capacity more robustly in case of fading (because 512QAM RX threshold is much better in 28MHz bandwidth than larger bandwidth),
- Even in case of very deep multipath fading, multi-carrier systems keep the bundle capacity at much higher level than systems using wide band carriers.



QAM	28 MHz	56 MHz	112 MHz
4	25	50	100
8	50	100	200
16	75	150	300
32	100	200	400
64	125	250	500
128	150	300	600
256	175	350	700
512	200	400	800

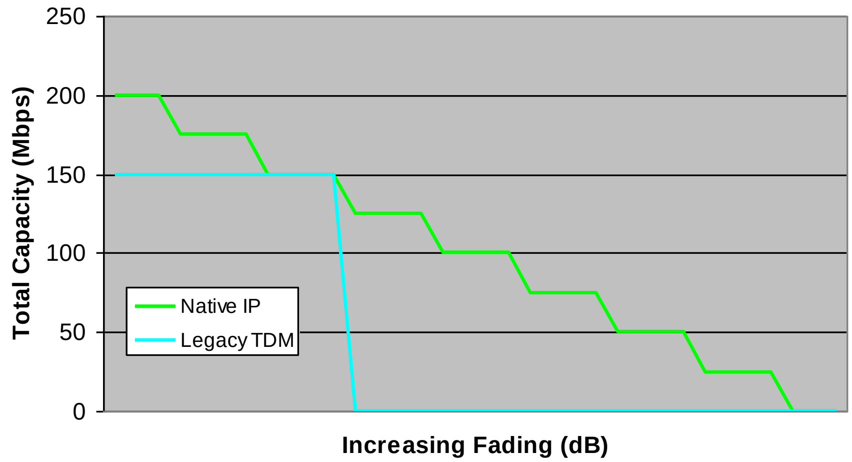
Reference capacity (Mbps) vs QAM format and bandwidth

THE OPTIMAL USE OF THE SPECTRUM

The adaptive modulation allows to solve the paradigm about high modulation format and relevant performances degradation

For any MW system, either conceived for access or trunk applications, it is surely fundamental to be capable to exploit at its best the available spectrum, meaning having the max spectrum efficiency possible (best ratio between transported capacity in Mbps and occupied bandwidth in MHz). Recently, the possibility to transmit directly native IP data on air allowed surpassing the spectral efficiency boundary imposed by traditional TDM systems: with modulation increasing to 512QAM and beyond, actually more and more capacity can be transported in the same bandwidth. In addition, thanks to adaptive modulation, the quality and availability degradation implicit in such higher order modulation formats is just impacting the extra traffic gained by the higher order modulation formats. As well, still thanks to adaptive modulation, the quality and availability of legacy traffic is improved, because the legacy capacity can be now split in sub-classes with different priority each, whose robustness is improved by the better RX thresholds of the lower modulation formats. Of course, the above is true only if the adaptive modulation process is hitless and QoS-driven (low priority packets are dropped first as soon as modulation switches from a high order to a low order format). To make it simple, let's see a graph showing the comparison between a traditional TDM system transporting 1xSTM-1 on one carrier and a native IP system working on the same carrier. Let's assume 28MHz bandwidth and let's assume that the maximum modulation for IP mode is 512QAM. From the graph we can see that the native IP transport has the following two benefits:

- During normal propagation (no fading) it allows extra capacity to be transported,
- During heavy fading condition it provides more availability for the high priority traffic.



In other words, the native IP enables granularity in the traffic, so that transmission is not just ON/OFF depending on fading (as it happens in TDM systems), but continuously liaising across the multiple classes of priority pertaining to the several modulation formats, and gradually reducing the capacity accordingly as soon as the fading increases.

The advantages of the adaptive load balancing mechanism in the multi-carrier operation: use spectrum resource as a single bundle, whilst taking advantage of the multi-carrier concept to optimize hop coverage and resiliency

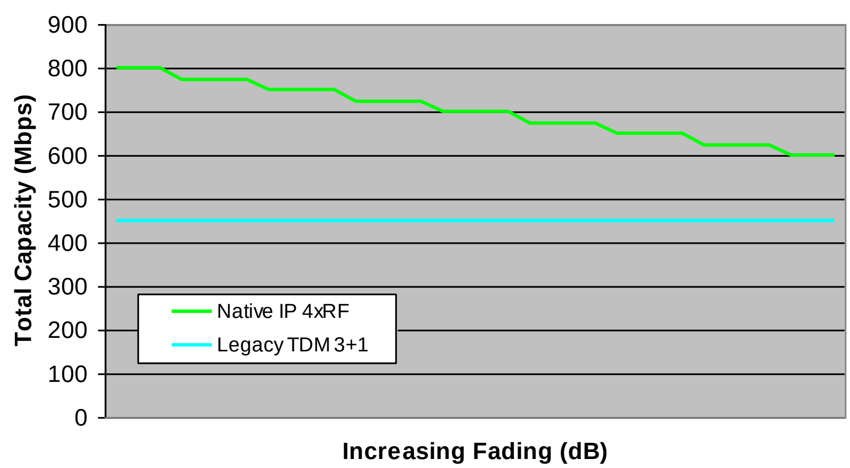
This analysis about the advantage of native IP vs. TDM transport in terms of higher throughput and higher robustness would be already enough to encourage any telecom operator to thinking seriously about migration from legacy TDM scenarios to native IP. The truth is that there are even many other advantages coming from the use of native IP compared to TDM. One of them becomes clear as soon as we start thinking “multi-carrier”: in fact, when we have a multi-carrier TDM system, each TDM carrier is totally independent from the others and as soon as one TDM carrier is lost, all the information being carried is lost, without considering that possibly other TDM carriers are transmitting lower priority traffic at a certain time. With the IP transport instead, all the IP carriers can be bundled together as a single radio aggregation group acting as a single radio bonding/trunking, as if it were a single carrier (but keeping all the advantages of the multi-carrier functionality that we mentioned in the previous paragraph). Such radio aggregation bonding in Harmony Trunk is implemented with adaptive load balancing, and is hitless and QoS-driven. Further, the distribution of data traffic among the RF carriers is carried out at the Layer 1 level (byte by byte) in order to assure the optimal use of the available resource of each RF carrier, with no leakages. Once such load sharing is implemented, every outage occurring on one carrier would be mitigated by the presence of low priority traffic in the full bundle stream as a whole, thus assuring that the capacity reduction caused by the outage would not affect any high priority packet, as far as possible. In other words, the difference with respect to the native TDM case is that in the case of TDM transport there is a 1-to-1 relation between each RF carrier and the traffic transported over it. In case of native IP, instead, there is not any 1-to-1 relation: the full spectrum is a shared resource where the packets are transmitted dynamically, giving priority to the most important traffic, and dropping just the lowest priority traffic, if it is in excess with respect of the capacity available at a certain time. It does not matter if and which carrier is in outage at a certain time: when this condition occurs, this is perceived by the data mapper just as a reduction in the total load balancing pipe capacity. This concept implies that in case of native IP transport there is not any need to use a dedicated RF carrier as “protection channel”, because the adaptive load balancing mechanism is intrinsically protected vs fading and HW failures. This is an additional advantage of the native IP transport vs legacy native TDM. As a fact, the N+1 configuration which is very familiar for TDM systems, where 1 protection channel is dedicated to work as reserve channel for N main carriers, is not applicable as a configuration for native IP systems, and this big advantage allows utilizing fully 100% of the available spectrum in the case of native IP operation. Let’s see this topic better looking at following table, which shows the number of RF channels actually used to carry user traffic in the two cases of native TDM in protected N+1 configuration and native IP with adaptive load balancing over the same total spectrum (i.e. N+1 RF channels):

When the multi-carrier operation combines together with adaptive modulation and shared protection channel in hybrid configuration: use 100% of spectrum for 100% of time

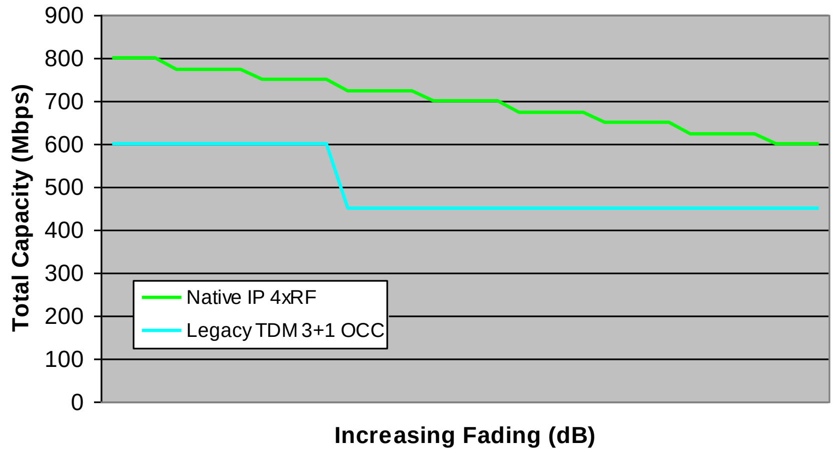
	Native IP	**Native TDM**
Normal Operation	N+1	N
Deep multipath fading or HW failure	N	N

It is clear that using native IP transportation, the spectrum use is 100% during normal operation, whilst in case of legacy TDM operation it is N/(N+1) < 100%.

Let’s see better the advantages of native IP vs TDM in case of multi-carrier operation, in conjunction with adaptive modulation: it means let’s revisit the latest graph shown above but extended to a typical N+1 case with N=3 with 28MHz bandwidth per each carrier. The result is really impressing: for TDM case, capacity is constantly at 3xRF carriers TDM capacity, meaning 3x150 Mbps; for native IP case, the capacity is fluctuating between a maximum capacity of 4x200Mbps and a minimum capacity of 3x200Mbps.



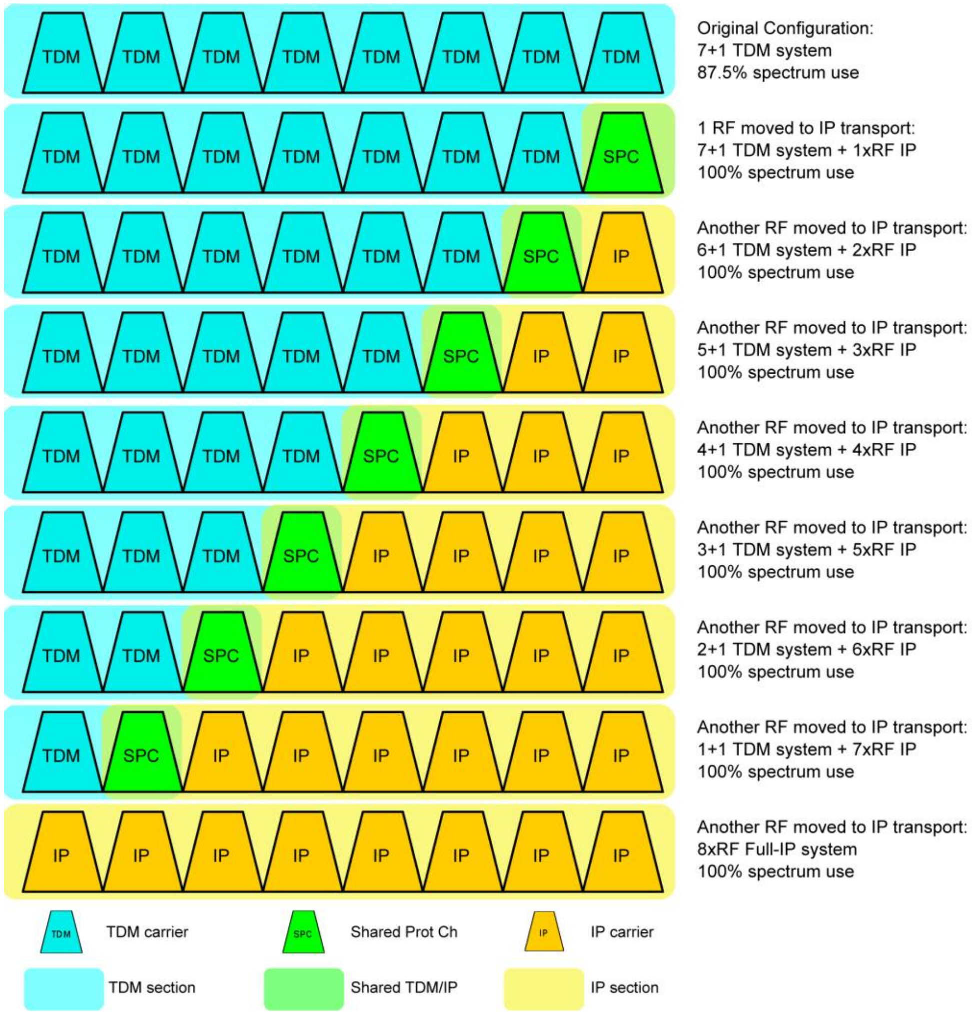
Even if we consider that the TDM system may use some Occasional TDM traffic function (meaning transmitting some low priority TDM traffic on the protection channel), the situation does not improve much, as shown in the following figure.



THE MIGRATION FROM TDM TO IP

One of the main concerns of operators nowadays is to choose a transport platform allowing smooth migration from legacy TDM to native IP with investment saving

All the advantages explained above clarify why the native IP transport is much more effective than legacy TDM in terms of throughput, availability and robustness. Other advantages could be listed, which are pertaining to the simpler handling of packets than circuits, which simplifies the complexity of switching sites, physical connectivity of equipment devices in nodal stations, data processing techniques applicability to packet data and so on. All these advantages justify the trend of most telecom operators towards native IP transport. This migration is especially crucial in MW Trunk systems, because operators have to liaise with existing large backbone networks dimensioned with large legacy TDM capacity, so that it is fundamental that the migration towards native IP transport shall be done smoothly, step-by-step, or better carrier-by-carrier, without traffic interruption and as far as possible without wasting any HW. From this point of view, the Harmony Trunk provides the optimal solution, because each transceiver of Harmony Trunk can work as native TDM or native IP via a remote setting. It means that any operator today can deploy Harmony Trunk in full TDM or Hybrid configuration, without fear of wasting any HW if tomorrow they will migrate to more extensive use of native IP. During the intermediate Hybrid configuration where at the same Harmony Trunk terminal some transceivers are working TDM and some transceivers are working native IP, the same controller unit will handle both TDM and IP sections, and this assures the smooth TDM-IP migration and even the possibility to implement synergy between the TDM section and the IP section. When we say “synergy” it means that the two sections TDM and IP are mutually interrelated to optimise efficiency in the spectrum use: in fact, TDM section needs to have a dedicated protection channel in the case of an outage on one of its carriers, and such protection channel can be borrowed to the IP adaptive load balancing mechanism when unused. This synergy allows Harmony Trunk to exploit the 100% of available spectrum not only in the case of native IP mode, but even in the case of Hybrid TDM+IP mode, because the TDM bearers are not protected by a dedicated RF carrier reserve, but by one of the carriers of the IP aggregation group. This synergistic mechanism is called “Shared Protection Channel” (SPC) and Harmony Trunk is unique in the market in implementing it (other vendors just use parallel transport of TDM and IP in the same terminal independently, with no synergy between the two sections). The following picture shows the gradual step-by-step migration plan for a 7+1 TDM system evolving to 8+0 full-IP carrier-by-carrier: starting from first step of the migration plan, the spectrum use gets 100% thanks to SPC functionality.



With Harmony Trunk you can upgrade RF carrier by RF carrier your spectrum from native TDM to native IP, without replacing any HW: just SW-definable

FULLY INDOOR OR FULLY OUTDOOR?

According to the microwave systems literature, MW trunk systems are traditionally fully indoor mount, meaning that the full system has to be mounted inside a rack to be housed in a weather protected and air-conditioned environment, and connected to an antenna via elliptical waveguide. In the past, the fully indoor mount concept was a pre-requisite for any MW trunk system, “MW trunk” meant “fully indoor” and vice-versa, however nowadays this equation is no longer true, and many vendors are actually proposing split-mount trunk solutions composed by ODU (to be mounted close to antennas and generally including RF parts only) and IDU (to be mounted indoor and generally including BB and MODEM) connected at IF level via a multitude of IF cables. In reality, even nowadays the most demanding telecoms operators still require fully indoor mount for trunk MW equipment, for several reasons:

- Fully indoor means that all the active electronics is protected in an indoor environment with air-conditioning and thus optimal resiliency.
- Fully indoor means that any expansion and/or upgrade activity can be done

easily by adding plug-in hot-swap modules in the main sub-rack indoor without any need to climb a tower to reach any active electronics device. This is especially important for MW trunk systems because scalability is a key factor: MW trunk is generally conceived with the plan to carry out future capacity expansions and or upgrades (e.g. migration from TDM to IP for one or more carriers) in the easiest way possible, as soon as capacity demand increases with respect to first installation.

The advantages of a backplane-wired solution for high capacity trunk microwave systems

- Fully indoor means that any maintenance activity (e.g. restore a faulty unit) can be done easily by non-skilled personnel, just by sliding in/out the relevant hot-swap module in the main sub-rack and avoiding any activity outdoor.
- Fully indoor means that all the electronics is connected via backplane, thus maximizing connectivity reliability and ease of installation, and minimizing site complexity because of minimal use of cables: no intra-rack cables are required in Harmony Trunk, but just user cables and power cables, whilst any IDU-ODU solutions need multiple IF cables running between IDU and ODU, besides grounding cables, power cables, user cables.
- Fully indoor means also that the RF branching is natively designed to ease any RF branching expansion and/or upgrade in such a way to prevent as much as possible any traffic interruption and to assure that the rule of "balanced TX+RX losses" is always matched without any special treatment.

All in all, MW trunk equipment is used to transport core backbone capacity traffic: losing one MW trunk connection means risking to lose complete connectivity with a region or sub-region, thus it is a very precious resource for any telecom operator, to be dimensioned and maintained carefully and the equipment chosen to fulfil such scope shall assure the needed reliability and resiliency. Harmony Trunk system complies in full with the above points and is first-in-class in terms of scalability and upgradability by making extensive use of plug-in concept from BB level up to RF level (innovative RF backplane with plug-in RF filters).
However, of course the "trunk light" outdoor solutions have some interest among many operators, especially when indoor infrastructures are not available or not large enough to house a complete rack for trunk MW. The reason for such success is that such "trunk light" solutions also provide some advantages which are not provided by traditional fully indoor systems:

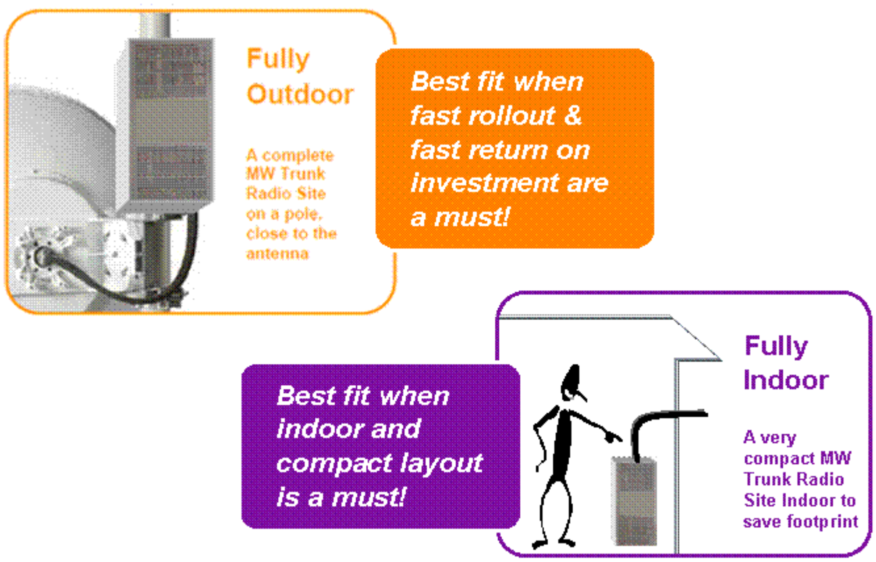
- Mounting the ODU close to the antenna means to avoid RF losses of the elliptical wg which connects the indoor-mounted trunk system with the antenna, thus giving system gain benefits.

In some cases the outdoor solution may provide significant benefits to MW trunk rollout and business case

- Avoiding the use of space in the indoor site means avoiding air conditioning, elliptical wg, dehydrator, wg accessories, and the indoor site itself, and the total site power requirement may be reduced, thus bringing consistent cost savings.
- In many cases a site is already fully outdoor (e.g. outdoor base station, outdoor access MW, outdoor AC/DC converter and battery system): in this case, it is quite normal that if a trunk terminal is needed in that site, it should have outdoor design and not fully indoor.

These advantages show that the indoor mount pre-requisite is not applicable sometimes. In addition, these advantages show that a fully outdoor solution would be even more suitable than a split IDU-ODU solution to match these outdoor needs. That's the reason why a new compact version has been recently added in the Harmony Trunk portfolio, which can be housed in outdoor cabinet for fully outdoor applications. The compact trunk cabinet for Harmony Trunk zero footprint basically combines all the advantages of the fully indoor version and the ones relevant to the outdoor mount, because it is still complying with the backplane concept and extensive plug-in modularity, but is based upon an outdoor cabinet concept (for mount in either tower base or close to the antenna), thus matching the outdoor cases needs. Each outdoor cabinet may house up to 4 RF carriers, thus configuration up to 8+0 can be achieved by using two cabinets (one for V polarization, one for H polarization). Indeed, the compact trunk cabinet for Harmony Trunk may be even mounted indoor, to suite those cases where indoor mount is still required, but a very small footprint is needed, and extensive multi-carrier expandability up to 16xRF is far more than enough.

Harmony Trunk combines the advantages of Fully Indoor and Fully Outdoor concepts, by providing two alternative, compatible solutions which may coexist in same network: just choose site by site the indoor or the outdoor mount, depending on the real needs



CONCLUSIONS

The stable demand for MW trunk equipment worldwide in years has shown that many telecommunications operators still see and value the advantages of owning a backbone network instead of relying on leased lines. Having an own backbone network is a good investment, and building it by means of MW trunk equipment in conjunction with fibre optics allows achieving a fast ROI thanks to the limited civil works needed for MW deployment. In this view, the Harmony Trunk platform, with its ability to suite carrier requirements for migration from TDM to Hybrid and Full-IP multi-carrier scenarios, is a best-in-class solution to build long haul, reliable and efficient communication links, always exploiting the available RF spectrum at the maximum extent. Its flexibility to be mounted as fully outdoor or fully indoor, in a compact version or very high capacity version had made it the right choice for many telecoms operators and public utility companies worldwide, who rely on Harmony Trunk to transport their backbone traffic resiliently.