Multisite system design for

Digital Mobile Radio (DMR) network

Version 1v0

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ABSTRACT

The digital mobile radio (DMR) standard appears very attractive for the professional mobile radio applications. It is a powerful digital solution that meets the major needs of users: digital encryption, good and constant audio quality, reliable data, GPS positioning without any disturb in audio, text messaging, telemetry, two TDMA channels in 12.5KHz (6.25KHz/ch equivalent), soft migration from analog to digital, low power consumption,etc..

DMR has all the advantages of a digital radio at the cost of an analog (conventional) one. These benefits may be partially missed when the coverage requested by the radio system exceeds one repeater. Some "key points" have to be understood to design an affordable, stable and user-friendly radio system.
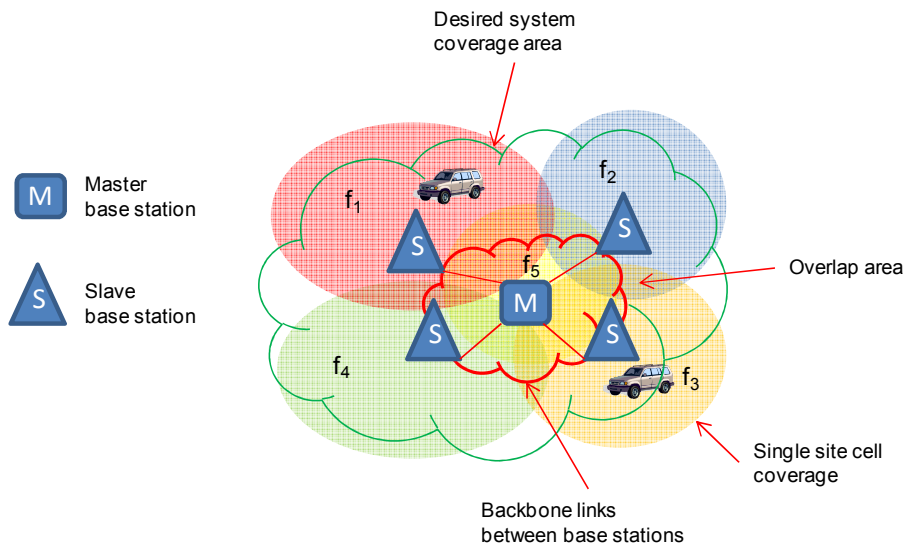
The main problem is the cell <u>handover</u> (site coverage changing) and <u>roaming</u> (research of desired group of users) in non trunking systems. These functions are not real time performed by DMR over the air protocol: the available mobiles/portables should scan frequencies to look at the best "home" base station. Due to the scanning and validation time during handover, a mobile may be "missed" for relative long time (minutes). This problem may be unacceptable in an urban environment in which the cells are changed frequently.

A robust and powerful solution that removes all multi-site limitations is to implement a single "big cell" with the same frequency over all the coverage area: this reduce to zero the time requested to reach a mobile or to find the correct base station. Simulcast solution permits the "click-less" base station changing during a communication also.
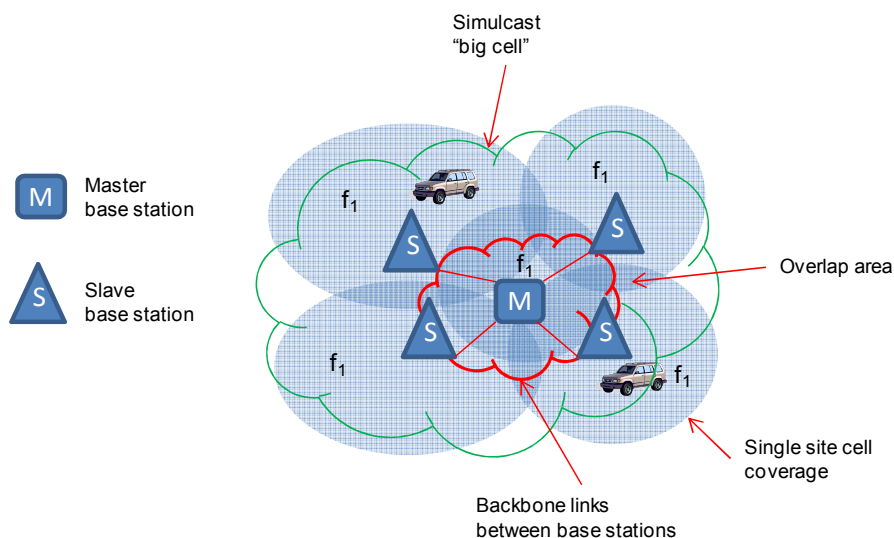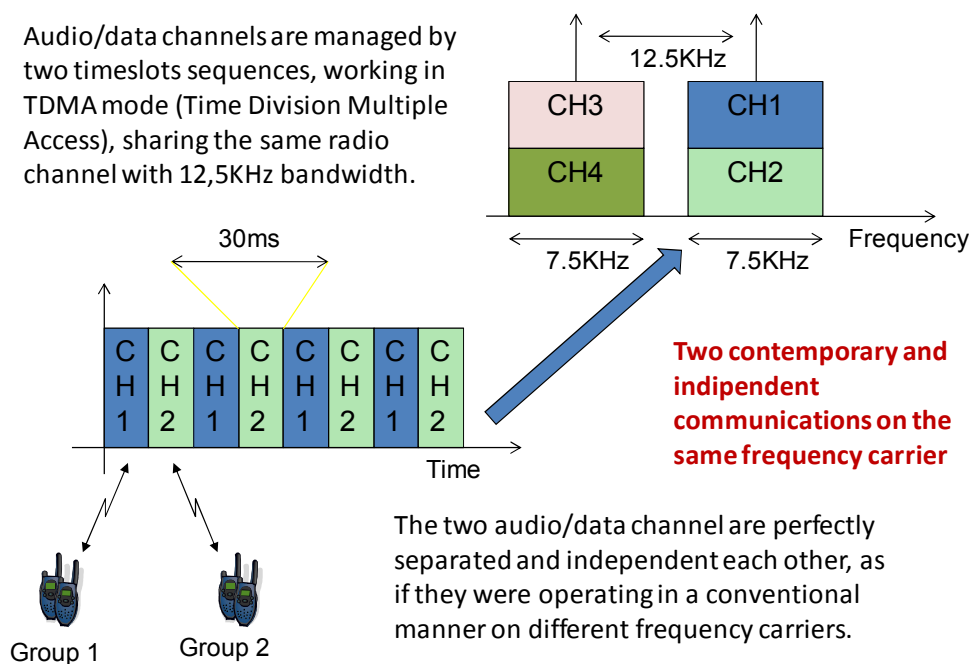

In the following it is described the multi-site realization with multi-frequency and with simulcast approaches.

DIGITAL MOBILE RADIO (DMR) IN BRIEF

DMR standard (ETSI TS 102 361 technical specification) is an open standard, defined in ETSI world by a working group established by the major world PMR equipment producers. The DMR standard was built following the guidelines of the PMR market requirements for digital flexible systems, able to give added value to the current analog systems, but at the same time to guarantee a *gradual migration* between the two technologies, safeguarding the investments made and specific operational requirements.

The sensitivity of a DMR receiver is about the same as the one of a traditional analog system, but the audio quality remains constant up to the sensitivity's limit and the coverage is slightly bigger than 12.5 KHz of the analog systems. This fact allows a *full reuse of existing infrastructure:* the transition from analog to digital DMR technology does not require any search for new and additional broadcasting sites to preserve the existing service coverage areas. Radio-electrical efficiency of the two technologies is substantially equivalent; it is indeed possible to improve communications at the field boundaries by equipping the stations with additional receivers to perform diversity reception. Furthermore, no need for new sites means that it is possible to reuse existing power supply systems, the same antennas and the same filters systems used for analog stations.

Audio/data channels are managed by two timeslots sequences, working in TDMA mode (Time Division Multiple Access), sharing the same radio channel with 12,5KHz bandwidth.

Two contemporary and indipendent communications on the same frequency carrier

The two audio/data channel are perfectly separated and independent each other, as if they were operating in a conventional manner on different frequency carriers.

DMR operating in digital mode assures flexible voice/data management: radio resource is optimized because it is shared by voice services and data services; digital voice communications can be performed without any interruption of GPS positioning updating service and with the ability of alarms signalling transit (thanks to the presence of two timeslots). Digital communication permits also an easy encryption of voice and data without degradation of quality.

DMR digital protocol is based upon two TDMA (Time Division Multiple Access) managed timeslots on the same 12.5 KHz wide radio channel. This means that through the same radio channel broadcast by radio network, two digital communications can be established, and the radio channel capacity is doubled. The use of two timeslots allows also to exchange control signalling while radio communication is in progress, in order to manage, for example, the communication priority or to remote control of the terminals functionality.

Digital radio systems based on TDMA (Time-Division Multiple-Access) technology, realize two virtual channels inside the same physical licensed 12.5 KHz wide channel. This means to double traffic capacity, at constant license price, because the physical channel are virtually doubled.

The modulation is constant envelope frequency type, in contrast with TETRA. This implies great advantages in terms of energy consumption: transmitters are very similar to their classic analog version, expensive linearization is not required, they can work in saturation mode (C class or superior) with energy saving and consumption compatible with solar panels systems. The modulator must have a flat frequency response between 0 and 5 KHz.
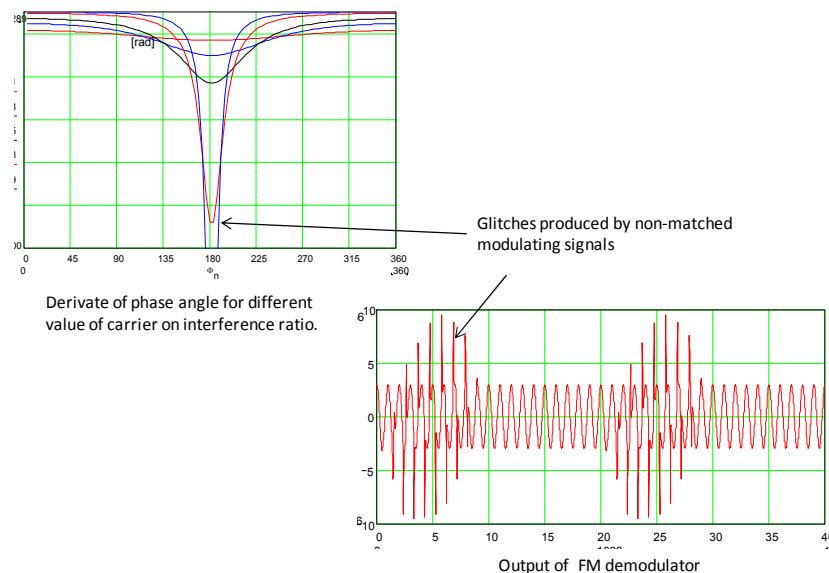
MULTISITE MULTI-FREQUENCY SYSTEM DESIGN

Multi-site approach

The multisite system approach allows a radio to be in coverage area changing position and to participate in a call originating at any site. In multisite system configuration, repeaters communicate among themselves using a back-end network. A call originating at a repeater is transmitted by all the repeaters of the system.

For a detailed explanation of the design of a multi-frequency system, it is advisable to see the chapters "2.6 Site Roaming" and "4.6 Multiple Digital Repeaters in IP Site Connect Mode" of the "Motorola Mototrbo[TM] system planner" guide.

In the Motorola DMR (Mototrbo[TM]) IP Site Connect system the traffic from one repeater is sent to every repeater. One repeater acts as the Master. The repeaters select one of the calls received during the "arbitration window" using a procedure that ensures that all the repeaters select the same call. After the selection, a repeater starts repeating the bursts of the selected call.

The geographically adjacent repeaters should use different frequencies. Their color code can be either same or different. It is not advisable to keep the same frequencies because in areas of overlap, without special precautions (see simulcast paragraph), there will be destructive interference as it is explained in the following figure.

Derivate of phase angle for different value of carrier on interference ratio.

Glitches produced by non-matched modulating signals

Output of FM demodulator

Terminal roaming

The terminals should be configured with a roam list that contains the list of channels, each of which is one site of the system. The radio searches through the sites list and selects the one with the strongest signal. The radio remains on this channel (home site) until the signal strength has dropped below a programmable threshold or when it has lost communications with the site, at which time it attempts to find a better home site. If a better home site is not found, it remains on the previous home site and continues searching.
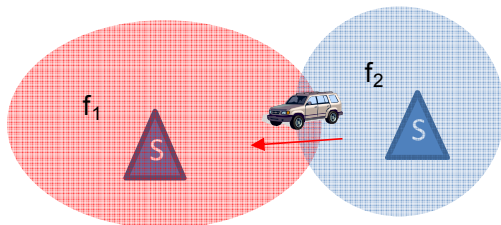
Mobile scan list:
f_1
f_2
f_3
f_4
f_5

While (passively) roaming, the radio temporarily leaves the current home channel and inspects other sites to decide if a better site is available. It is important to note that since the radio is temporarily away from the home channel, it is possible to miss the beginning of a transmission or a selective call or a text message. Due to the RSSI method of roaming, the threshold should be selected to maximize the chances of late entry to voice calls when a radio will leave one site. If the roaming RSSI threshold is too low, the radio will remain on a low signal strength home site even though there might be a stronger site available. If the roaming RSSI threshold is too high, the radio will be roaming in full coverage of a repeater when not required and may miss communications.

Base station beacons

The site search based on signal strength works well when the repeater is transmitting, but the repeater should be de-keyed when not in use due to the shared-use environment. If there is no activity on a system, the repeater should be configured to transmit a beacon (a periodic short transmission), when not transmitting and when there is no interference.

The duration of the beacon grows with the growing of the number of sites in the roam list. The interval of the beacon is a function of the shared use rules of the channel and how quickly a radio is required to roam when there is no activity. If the repeater's beacon interval is set too long then it may be possible that the radio has roamed into a new site and has yet to receive a beacon.

The ratio of the beacon duration and beacon interval should be kept low on a shared use frequency system. It equates to how often the repeaters transmit while there is no inbound radio activity; the target ratio should be between 5% and 10%. In other words, if there is a need to increase the beacon duration, the beacon interval must also increase in order to keep the correct ratio.
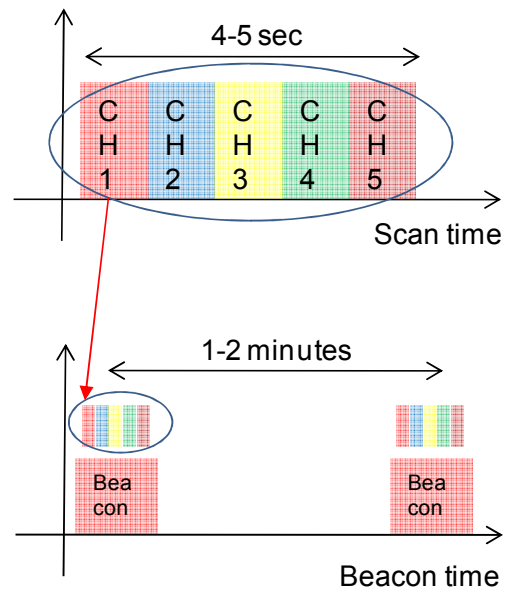

Real cases

The radio frequency field rarely follows a simple circular coverage. High buildings, hills and tunnels may produce abrupt change of the field and require a different base station cell.

In a dense overlapping coverage (urban) environment, a radio user may be within coverage of three to four sites at a time. The scanning time of 5 channels roaming list requires about 4,5" so bacon may be 5-6" long and it should be send every 60" (10% in time) from the base stations.

If the subscriber does not receive a beacon in the expected duration, it assumes it is out of range of the repeater (or that the repeater has failed) and attempts to roam to another site. If the repeater beacon is sent out every one minute, the radio may be one minute deep into the site before it sees the site and roams to it. Similarly, when roaming with no system activity, a radio may be one minute outside of the site before it attempts to roam.
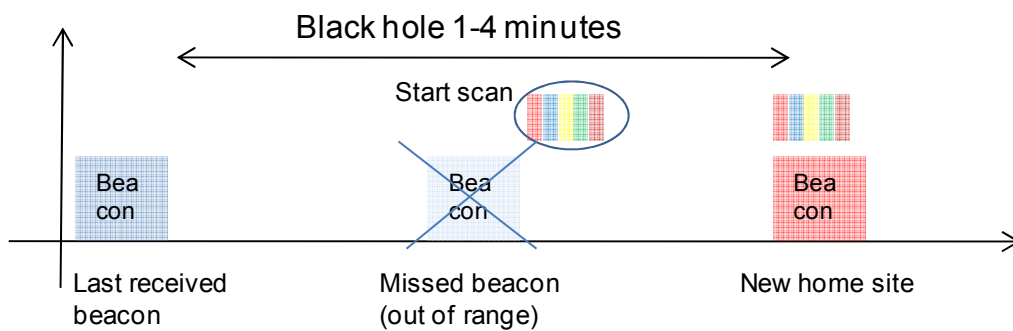

In urban environment the time it takes a radio user to move from the coverage of one site to another is in the range of few minutes or less (e.g. in/out in a tunnel). **This may produce an unacceptable one minute out of communications every few minutes!**

In a rural environment the situation is more favorable due to the higher time required to move from a site coverage to another and for less overlap areas. The consequent ratio of the communication time missed over the total time could have an acceptable value.

MULTISITE SIMULCAST SYSTEM DESIGN

What is simulcast?

A simulcast radio network is a very powerful radio network in which all the repeaters are active on the same frequency and at the same time.
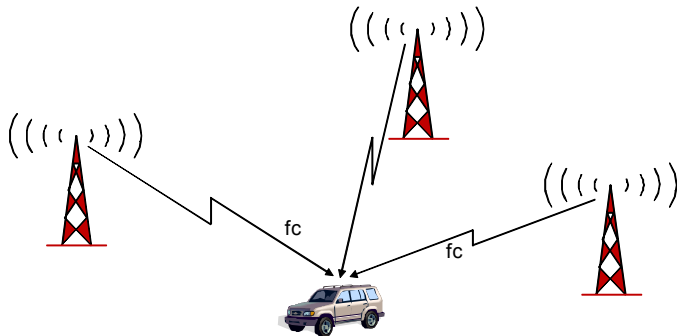
Main advantages:
- ∞ No terminal scanning needed;
- ∞ Automatic and continuous roaming and hand-over => Easy to use, fast set-up time;
- ∞ Functioning like single "big repeater" => automatic and simple conference call operation;
- ∞ All stations directly connected to the network => Integrated communication sys;
- ∞ The same RF channel over all Network => no change of channel in the coverage area.

The simulcast solution is the best in case of emergency due to easy and fast "open channel" mode of operation:
- ∞ all people involved in emergency situations can listen all communications so they are continuously informed about the critical situations;
- ∞ the regulation of network access is made by user, absolutely more intelligent and efficient than a trunking SW logic.

The communications in the network are normally repeated in "transparent mode". It means that no specific signalling is required by the network to govern the mobile terminal.

The coverage area of every single simulcast channel could be expanded easily by adding some simulcast base stations. These simulcast base stations will be integrated in the network with few operations at network level only (nothing is requested on mobile terminals).

The simulcast network removes the need of scan on mobiles and portables, assures real time roaming and hand over during the call and reduces license costs.

Technical aspects

To perform a simulcast radio network it is not enough to set the same frequency over all the repeaters of a multisite network. Due to the non-linear characteristic of the FM demodulator (extracts the arctangent of the arrival angle), it is mandatory that the emissions from two or more repeaters must be exactly the same.

To work properly, an analog simulcast radio network requires:

- ∞ Frequency difference between RF carriers < 10Hz
- ∞ Amplitude response between +/- 0.5 dB over all audio band
- ∞ Signals band coherence (not guaranteed in case of FDM channels)
- ∞ Absolute delay spread less than 20µs
- ∞ Phase error less than 10deg

A digital simulcast system requires also:

- ∞ Bit exactness transmission
- ∞ Absolute delay spread less than 1/10 of symbol duration (20µs @4.8Ks/s for DMR)

The analog requirements are well known and the absolute symbol delay is similar to the analog one. It is important to note that the bit exactness involves special attention on DMR protocol aspects. In fact DMR protocol is typically asynchronous and the actual value of some bits depends of the previous history of the communication.

At the end, to build a digital (DMR) simulcast network, it is necessary a special design of the base stations that assures the possibility of fine delay adjust (10μs step), perfect synchronization in frequency and timing, with special algorithms for protocol alignment. It is very hard to obtain these features from a standard repeater.
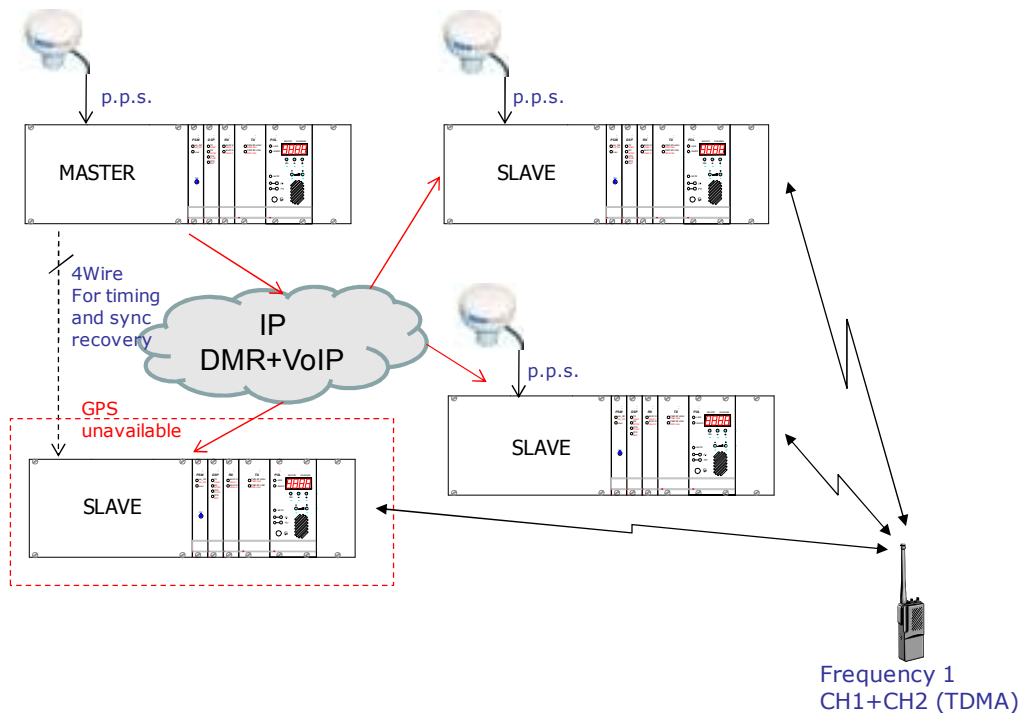
Another essential function of a simulcast network is the voting process which is the method by which the best signal received from the network is continuously selected. In analog the Master station is able to "extract the good" of each signal received from RBS and to create a summary one with an improvement of input signal to noise ratio. In Digital mode (DMR) every timeslot received from all the base stations is selected to found the error free timeslot or the maximum likelihood one in absence of CRC (e.g. voice). A high performance, real time voting system performs a "very large diversity reception" over all the base stations involved in the call. The global effect on quality compared with the multi-frequency approach is superb.

The best signal (analog or digital) is sent back to all base stations in "multicast" mode. This procedure reduces significantly the bandwidth required to the backbone interconnection network.

Forget the past experiences of trouble simulcast
The simulcast networks are not very popular in the entire world due to the difficulty in achieving the precise technical requirements illustrated previous. A lot of system integrators tried to assemble simulcast network from conventional repeaters adding synchronizer and (analog) delay line. The result was often a network with a lot of difficulties during set-up operations, with frequent and onerous maintenance operations, and, at the end, with low customer satisfaction.

In Italy, like other countries, the geographical constitution and other factors forced the constructors and the system integrators to find good simulcast solution. The revolution in simulcast performances was built in the 90' with the use of Digital Signal Processor (DSP) devices directly inserted in the analog base station. The performances of the network were so good that the most part of professional mobile radio networks in Italy are simulcast one!

The latest challenge is digital simulcast network. Starting from analog experiences, Radio Activity modified its DSP based software radio, to perform DMR protocol. All development was done to achieve optimum performance of digital simulcast and the field confirms this design. Sophisticated algorithms recover accurate sync (time and frequency), allowing (automatically) for adjustments of the delays and the alignment of the Protocol to achieve emissions at the bit accuracy. DSP includes the real time voting system and the network base station control layer.

The digital communications has the advantage respect to the analog one of forward error correction and adaptive filtering functions. These functionalities reduce the amount of bit error rate with a consistent improvement of audio and data quality in the overlap areas.

Digital or analog mode is automatically selected from the incoming signals modulation for facilitate a smooth transition from analog to digital. A lot of base station configurations permit to realize simulcast networks with various backbone Links: TCP/IP (also wireless one), E1/T1, twisted wires, narrowband radiofrequency link, and mixed also:
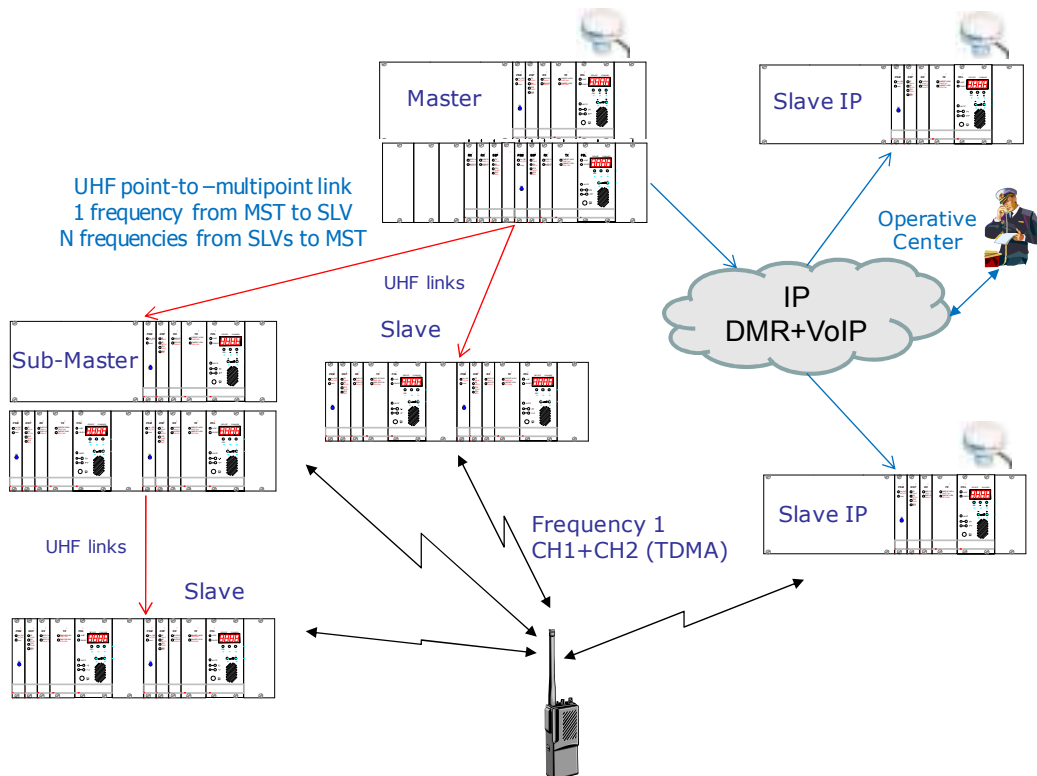
All necessary functions (synchronism, voting, VoIP, remote control, network management, call control, etc.) are integrated in the base station without the need of external expensive and tedious to cabling devices.

For more information see the detailed Radio Activity technical documentation.

CONCLUSION

The DMR technology is very attractive and represents a good compromise from price and performance.
Unfortunately is not available the protocol to realize effective radio systems multi-site and multi-frequency. Continuous cell changing with consequently communication loss may have destructive effect on user satisfaction.

Instead with the simulcast approach the entire network operates like a single "big repeater". In simulcast network hand-over (base station changing) and roaming (research of desired group of users) are fully automatic, fast and without interruptions (click-less). The performances of the network increases dramatically: no missed communications over abrupt cell change.

The simulcast solution offer many other benefits like for example the fact that the coverage area of every single simulcast channel could be easily expanded by adding some simulcast base stations. In fact the integration of these base stations in the network can occur with few operations at the network level only (nothing is requested on mobile terminals).

The Radio Activity simulcast network is a really "plug and play" solution for professional users.