Simulcast digital mobile radio networks
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INTRODUCTION ON DMR MULTISITE AND SIMULCAST SYSTEM

ABOUT RADIO ACTIVITY

Radio Activity is a young and dynamic electronic engineering company specialized on design and production of wired and wireless communication equipments and systems.

The engineering team has completed more than 20 years of experience in RF, DSP and networking at major telecommunications companies. Radio Activity has developed advanced techniques for analog and digital simulcast mobile radio networks and numerous products for data transmission and communications management.

Radio Activity is a node of a network of excellence’s partners. The research and the development carried out inside the Company involves Radio Frequency, Digital Signal Processing and IP networking fields. The Company, taking advantage of external professionals of highest level with multidisciplinary skills, is able to create, each time, work groups in order to solve the most complex projects and to satisfy the most demanding Customer’s requirement. The result is a flexible and light structure, to reduce the fixed costs and to allow to always take advantage of the best available technology.

Radio Activity in few years has furnished more than 1500 base stations for emergency and essential services applications to a number of important Customers: Agip, Wind, Enel, Edison, Fire Brigades, Police, Motorways, Railway, Civil Protection, Rätia Energie AG, RWE, etc...

MULTISITE DMR SYSTEMS – MULTICAST/SIMULCAST

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 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.

To learn more about DMR multisite solutions we suggest to see:

∞ the latest edition of the documents on Radio Activity web site:

 o ENB25 - DMR multisite sys design
 o ENV2 - TCP-IP simulcast
MULTISITE MULTI FREQUENCY APPROACH

In multicast approach, 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.

The main problem is the cell **handover** (site coverage changing) and **roaming** (research of desired group of users) in non-trunking systems. These functions are not real time performed by DMR (tier II non-trunking) 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.

MULTISITE SIMULCAST APPROACH

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.

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. To obtain this result it is necessary to implement a number of algorithms to assure perfect alignment between the signals broadcasted by different base stations.
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;
- Maximum spectral efficiency due to use the same frequency in the overlap 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 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.**

The communications (private or group type) inside the mobile radio system may be:

- mobile to mobile in direct mode (short range). Normally they operate in the output frequency of the network so they can speech among them and, at the same time, they can listen the communications coming from the network
- mobile to mobile in repeater mode (long range). The mobile equipment use a frequency to access the network and a second frequency to listen the communications coming from the network (semi-duplex). The network is equal to a single “big” repeater.
- mobile to dispatcher in repeater mode. The communications are in semi-duplex mode as the previous case. The dispatcher has the priority in the communication. All the communications from the mobile and from the dispatcher could be listen by all equipment.
- mobile to dispatcher in private mode. It is the same of previous case but the communications from the mobile could are listen only by dispatcher.
- mobile to telephone line in group or private mode. It is possible from a mobile to perform or receive a telephone call from a PABX or a PSTN line (it needed the RA-TI-XX option).
The network has its natural termination in the Control Room/Dispatch Center where all communications are managed. A Dispatch Center can be connected directly to the network through an Audio Gateway or can be connected through a radio path using fixed radio station. Many solutions are available depending on IP availability, cost and needs of the user. The following figure explains some application examples.

**SIMULCAST SOLUTION -> EXPANDABILITY**

Every channel of the system is independent from the other channel. The communications in one channel can be transfer to another channel only by a junction at master/Central Office level.

A system with N channel is the easy overlap of N separated simulcast networks. Note that a channel may be a single frequency (analog) or ½ of frequency (digital DMR). The following drawing explain this concept:
Every group of users communicate in exclusive mode in the own channel. In every channel can operate more than 1 group but, normally, they should have similar operative functions.

Every new simulcast channel can be added (with the necessary RF branching operations) without modify the other existing channels and without service interruptions.

There are virtually no limits in the number of channels of a system, the problem could be the branching system and the number of antennas required on sites.

The area of coverage of every single simulcast channel could be expand 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 request on mobile terminals).

**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 right level of matching in the base stations. 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.

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Simulcast digital mobile radio networks
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 functioning is automatically selected from the incoming signals modulation to 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.

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

Simulcast type networks operate on the same radio channel on the whole coverage area. Communications can be both open and selective channel, semi-duplex mode between mobile terminals or duplex mode between Central and terminals. The network will make the automatic selection of accessing terminals and will broadcast the signal on the same frequency throughout the coverage area. The terminals are served regardless of their position as if they were covered by a single repeater.

Radio Activity has a very powerful product to make simulcast network. The networks are based on the standard radio product RA-080 / RA-160 / RA-450 / RA-900. These radio implement all the necessary functions for high performance simulcast networks (timing and synchronization recovery, delay and response equalization, voting system, ...).

The Radio Activity base station is the ideal “basic block” to build simulcast or multicast radio networks based on the most common media supports. The network will operate in analog or digital (DMR) or in both (dual) mode with automatic selection.

The base stations of the RA-XXX family are configurable to work in simulcast network with many different connection links (backbone network):

- General purpose IP backbone (microwave, fibre optics, LAN, ...)
- Narrowband duplex radio links (UHF/VHF)
- 2/4 Wire leased/PSTN lines
- Mixed IP / radio link / wired

The flexibility of the RA-XXX base station allows a very large applicability of simulcast solutions over a number of real cases. The most used network structures may divided on the base of the backbone characteristics in two main groups:

- IP based backbone
- Narrowband RF linked

In the following chapters it will be explained the main common algorithms and the peculiarities of these simulcast solutions.
Simulcast digital mobile radio networks

**NETWORK FAMILIES**

Simulcast networks made by Radio Activity base stations may be divided in two basic family, depending on their backbone connecting system:

- IP-based backbone
- Narrowband RF linked

**IP-BASED NETWORK**

The IP based network is the ideal solution when an affordable IP backbone is available. This is the most common application of the Radio Activity base stations. Every base station runs in a full LINUX operative system that allow a very powerful and stable connections to a LAN backbone network through the local Ethernet port.

An important distinction between an over-IP system and a conventional (switch-based) one is that with a IP system there is no central switch, thus eliminating a critical point of potential failure. Instead, full signaling is made by IP (Internet Protocol) network technology to provide reliable data routing between network components. This combination of IP technology and the advanced DMR communication standard produces a feature-rich solution with a surprising degree of flexibility and resilience.

The synchronism are normally recover by the internal GPS receiver and the algorithms inside the base station perform all the needed functions for a best quality simulcast system. A TCP-IP backbone connectivity is very attractive to build professional radio networks. Since today it was very hard to implement a simulcast network over IP due to the instability of delay and time inaccuracy.

The channel group delay due to the electrical interfaces is identical in all stations

Absolute delay may differs continuously due to IP asynchronous transportation protocol (random delay)

Propagation delay due to mobile distance from the base station remains unaffected

TCP/IP backbone

The system needs a synchronism source to re-align the asynchronous signals coming from the IP backbone

Now Radio Activity has open the way to do it with many advantages:

- UDP/TCP-IP is the most common protocol in the world: standardization reduces dramatically the costs
- the IP world is well known and a lot of technicians are able to operate efficiently on it
- the communication redundancy is intrinsically assured by the protocol
- every base station is identified by an address (IP) instead then a (fixed) connection: it is easy to expand a network adding new base stations!
Simulcast digital mobile radio networks

- All communications are carried out in the same digital format (the analog one also) without any noisy conversion and avoid periodic tediously audio level adjustments

- A unique ETH port connects several base stations: this cuts the cabling costs and reduces the probability of failure

- Lower cost and lower bandwidth requirement respect to E1 solution

- A lot of customers has got a proprietary IP infrastructure for video-surveillance, remote controls, and other services: using the same infrastructure reduces the maintenance costs

- Simple redundancy implementation with “Alias Master” base station

Due to the intrinsic “relocation” of the peers in a IP network, this kind of solution is geometry independent and matches very well the common configurations as:

- Tree networks composed of nodal stations from which more "arms" depart towards stations downstream. This approach is hierarchic with a main Master station following to some level (nesting) of Sub Master and Slave stations.

- Linear networks consisting of a chain of stations, placed in series and connected via optical fibre or twisted pairs or multiplexes, to cover areas along highways, railways, pipelines, power lines and so on.

This solution presents a very good overall cost figure using very common and cheap IP network devices often just present in the Customer infrastructure.
In this kind of network the connections between the base stations are made by point to point radio links between Master and Slaves, with the ability to route through Secondary Masters.

The use of narrowband radio link allows to realize networks when the distance to connect is very large (100Km or more) or when the radio path isn’t in direct visibility.

The radio stations are very compact, making audio connections between link and local transceivers directly in a 4Mb/s digital format. All required functions (Voting, compensation for delays, synchronization) are integrated in the station.

The standard configuration is a star networks with Master station in the centre links with the Slave ones implemented by radio devices in the UHF range integrated in the same radio stations. The Master station uses multiple receivers array (one receiver each Slave/Sub-Master) and a single transmitter to send back to the Slaves the best signals.

Carriers and time synchronization are carried out by extracting the information from the data streaming coming from the Master station. No GPS receiver is required.

The delays compensation is also obtained through the techniques described in the preceding paragraphs.
Thanks to the algorithms implemented on DSP units for automatic equalization of signals and synchronism recovery, it is possible to realize simulcast radio networks with some base station connected through IP backbone (fibre optic or radio) and some other connected with narrowband radio links.

The same base station in an infinite ∞ application’s variety

This topology may be useful to extend coverage area starting from a main IP backbone. A main IP connection from microwave or optical fibre support may connect a part of the base stations (included Master) and some RF links may connect remote base stations.

Some care has to be take in the synchronism and delay matching of this kind of network.
**NETWORK CONFIGURATIONS**

**IP-BASED NETWORK**

This is the most common application of the Radio Activity base stations. Every base station has got an Ethernet port to connect to a LAN backbone network. An important distinction between an over-IP system and a conventional (switch-based) one is that with an IP system there is no central switch, thus eliminating a critical point of potential failure. Instead, full operating is made in IP (Internet Protocol) network technology to provide reliable data routing between network components. This combination of IP technology and the advanced DMR communication standard produces a feature-rich solution with a surprising degree of flexibility and resilience.

**BASIC FUNCTIONING DESCRIPTION**

One base station of the radio network works as “Master” station. It require a fixed IP address. The other base stations are configured as “Slave” stations with an IP static or not.

Through the LAN, the Slave base stations search the Master one and then they log themselves to it. The master governs the radio network sending timing and related information to the slaves.

The incoming signal from a terminal equipment is received from one or more base stations. All base stations receiving a valid signal send it to the master station via the Ethernet interface through the LAN backbone. The master station waits the arrival of all signals and then performs the selection of the best signal (voting system). The master selects the incoming signals continuously on the basis of signal/noise (analog) or maximum likelihood (digital DMR).

The master station sends back the best signal to all the slaves via the Ethernet interface through the LAN backbone utilizing a multicast IP protocol.

All the slaves synchronize the signals received from master on the local GPS signaling base. All the base stations synchronize also their timing, protocol history and carrier frequency to the GPS. The synchronization procedure requires less than 1-2 minutes to reach the requested precision after a “cold start up”. Thanks to the very high stability of internal clock sources in conjunction with sophisticated network algorithms, the synchronization remains good enough up to 8 hours after GPS missing.

Where the GSP signal is not available or it is “too evanescent”, it is possible to recover all precise synchronisms via a twisted pair of copper or a 4Wire interface (e.g. from a fiber optics MUX). Radio Activity develops other methods for synchronism recovery, contact Factory for details.
Note that the GPS is not needed in the case of multicast (non-simulcast) applications. In this case the algorithms based on the TCP-IP time stamps, corrected by Radio Activity “fine timing over IP” methods, perform a sufficient synchronizations of the base stations.

The Radio Activity simulcast or multicast network supports dual mode operation, that is, it can recognize if the incoming signal from a terminal equipment is analog or digital and configure itself as analog or DMR simulcast network. In the first case the voice will fill the entire channel (no other contemporary communication is allowed) and it will be compressed in quasi-linear format to be exchanged between stations through Ethernet connection. In the latter case the network will support two contemporary DMR communications (both data and voice) over the two timeslots. Full DMR features are supported.

If DMR terminals are programmed in scan mode, they can perform communication both with analog terminals in analog mode and with DMR terminals in digital mode.

**NETWORK REDUNDANCY**

A Master or a Sub-Master station is able to manage up to 32 IP peers where the IP peers may be Slaves base stations, Sub-Master base stations or RA-TI-XX audio interfaces.

Combining one Master with some Sub-Master in a hierarchical structure, it is clear that the number of base stations insertable in a network may be enormous as $32^N$ where N is the nesting index.

The Sub-Master station may be useful to realize the network with a some redundancy, where it is preferable to use more than 1 Master station to maintain the communications in the case of failure.

A very interested feature implemented in the Radio Activity IP based simulcast network is the “reserve Master” station or “alias Master” entity. Where the extension of the network is large or when a very reliable radio service is needed, it is possible to create a redundancy setting two Master base stations placed in different geographical position. The “alias Master” operate normally as a Slave base station until it doesn’t receive the “alive” messages from the Main Master. In this case it change its role in Master. Every Slave base station knows the IP address of the main Master and the IP of the “alias” one. When the main Master disappears from the IP network, every base station change the registration to the “alias Master” automatically restoring the network functionality.

Radio Activity is able to furnish the radio base station in 1+1 (main + spare) configuration. These equipment are made of two complete radio transceivers 1+0 sharing the same branching therefore all the functions, RF and IP routing, are doubled. The 1+1 equipment provide two line connectors in which input and output lines are physically paralleled, two Ethernet port with different IP addresses. By an internal algorithm a base station surveys the other and changes status in case of failure or on
timeout request. The timeout is useful to equilibrate the use of the two base station and to be sure that the spare will be ready when effectively needed.

Finally, in the event of a single radio site becoming isolated from the network it can continue to operate in standalone mode until such time as normal network communications are restored. Any sites still able to communicate with each other can also continue to work together whilst temporarily isolated from the main part of the network. The base station remains synchronized therefore a communication involved two local base station may be correctly broadcasted during a LAN interruption also.

NARROWBAND RF-LINKED NETWORK

A lot of users need narrowband radiofrequency link to connect the base stations of the network. These links operate typically in licensed UHF band, they can perform rugged and stable communications in “non-visibility” conditions also.

The “RF linked” solution has the following geometry:

![RF Linked Network Diagram]

The operation of this type of network may be summarized as follows:

the radio signal emitted by a peripheral device is received by one or more receivers on the network, all tuned on the same frequency, and sent via UHF links to a comparator, which is located on the master (or sub-master), which in turn shall continuously select the best one in terms of signal/noise (analog) or maximum likelihood (digital DMR).

Selected signal is then sent back simultaneously on a frequency, obtained by the digital synchronism clock worked out by DSP, to the various transmitters of the network which provide to broadcast to the area of coverage of the system. Radio mobile coverage areas become in this way very wide, well beyond the capabilities of a single repeater, offering at the same time to users of the network the same operational ease as a single repeater.

In more detailed view, it can be be the up-link signal path in the next example:
The real-time DSP voting selector on the master station chooses the best signal (greater S/N for analog or maximum likelihood for digital) incoming from the SLAVEs and sends it back to all the SLAVE stations. One different frequency is needed in the links from every slave station. Only 1 frequency is needed from the master station to the slave ones (the information is the same for all slaves):

The DSP on the SLAVE stations perform automatic carrier and timing synchronization (it is recovered from a short digital burst from the master station), delay compensation and audio equalization. The GPS receiver is not required in this application due to the constant delay offered from the digital radio links.

The master station could be equipped up to 9 receivers (it can “see” up to 9 slave/secondary master stations).

A very integrated base station with two transceiver in the sample 19” rack is available for this applications. Radio stations are very compact, making audio connections between link and local
transceivers directly in a 4Mb/s digital format. All required functions (Voting, compensation for delays, synchronization) are integrated in the station.

It is available the sub-master station for very large coverage area:

The sub-master station operates like a master station with an additional transceiver that perform the link with the primary master station. The sub-master send the best signal selected from its salves to the primary master and it send back to its salves the signals receiving from the primary master.

The sub-master recovers and regenerates all synchronism and signaling for correct simulcast operation.