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The Many Benefits of Digital Simulcast

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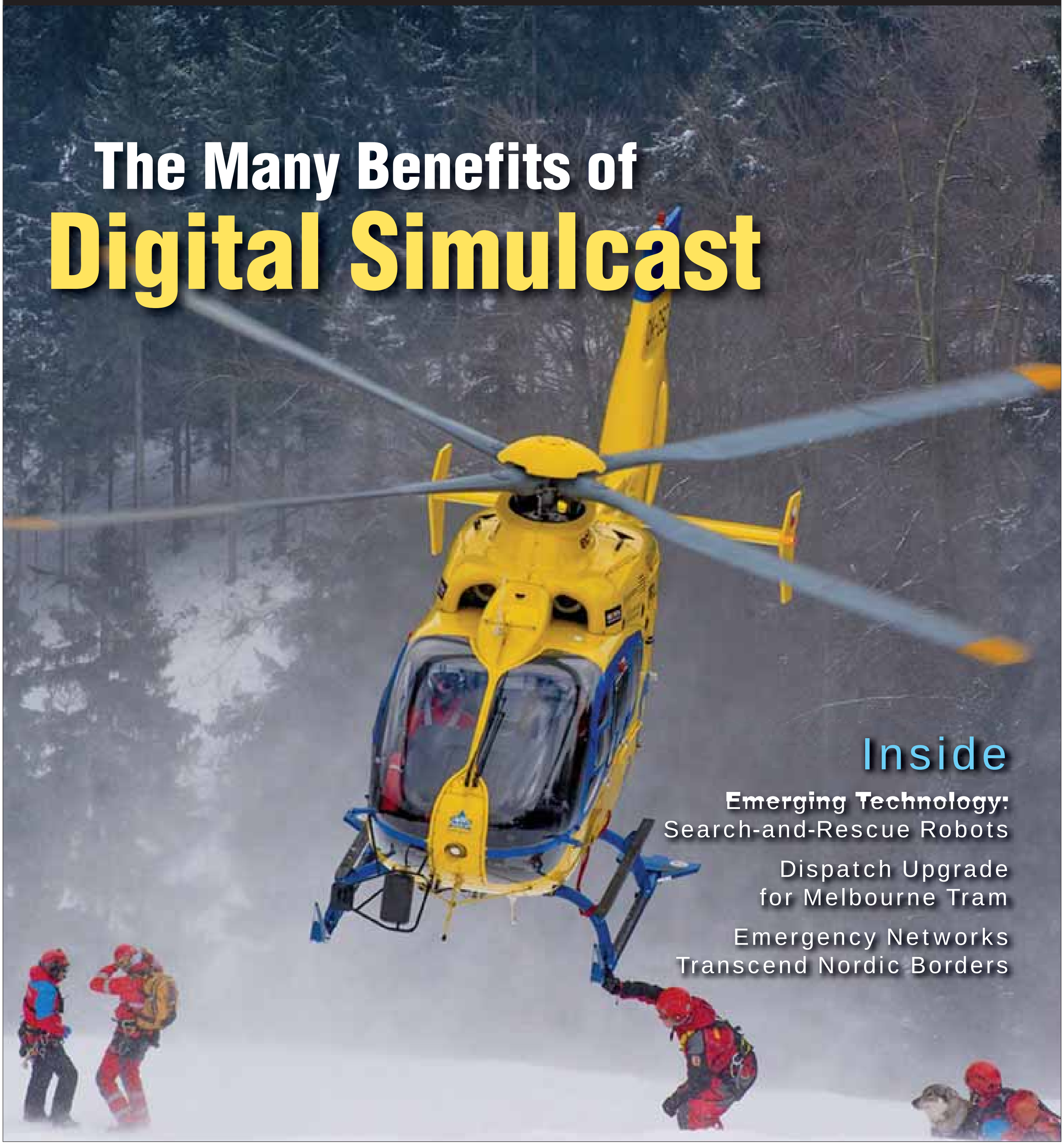


Digital Radio

Revitalizes Simulcast

Some digital professional mobile radio (PMR) technologies can support simulcast, offering numerous benefits.

By Roberto Marengon

The Czech Mountain Rescue National Team uses seven digital simulcast systems.

Photo courtesy Czech Mountain Rescue National Team

Early versions of analog simulcast systems were often chosen because of their spectrum efficiency, not their quality. Radios designed for digital modulation are opening a new era of simulcast applications, thanks to their intrinsic matching. A new generation of simulcast can also support digital communications, providing essential benefits and eliminating previous challenges. This article synthesizes concepts that may help modify common thinking about simulcast.

Simulcast Defined

In a simulcast radio network, all repeaters are active on the same frequency — both transmit (TX) and receive (RX) — at the same time. Therefore, a mobile terminal perceives the entire radio network as a unique "big" repeater, capable of covering the entire coverage area. There is no need to install additional hardware or software on mobile terminals. In fact, devices will move from cell to cell without the need for scanning or registration because the channel remains the same everywhere.

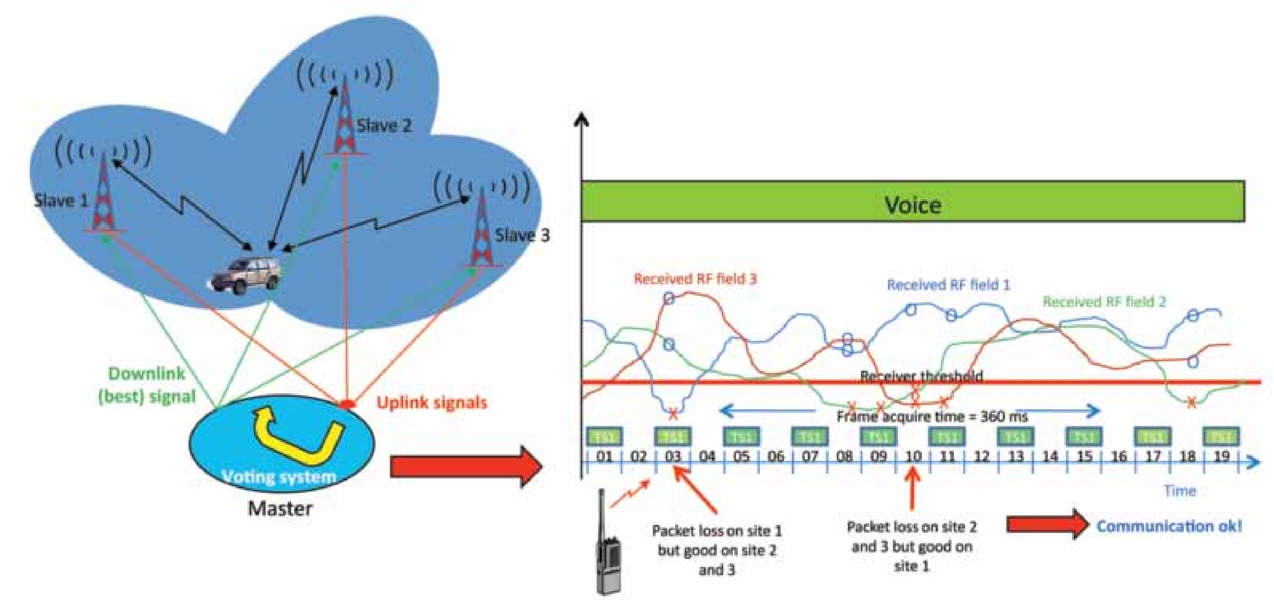
However, building a simulcast system does not simply entail setting all repeaters on the same frequency. Because of the non-linear frequency demodulation process within a mobile terminal, special algorithms must be implemented to ensure good quality in overlap areas — parts of the coverage area where RF fields from two or more transmitters converge. Because mobile manufacturers don't install special equalizers in their receivers, design efforts revolve around repeaters. Thanks to their high grade of matching, the advent of digital radios allowed the perfect alignment among broadcast signals, a necessary condition for simulcast.

A common myth about simulcast is that when a user is in an overlap area of two transmitters with the same RF field and opposite in phase, the user will experience a hole in the receiver signal. This statement appears true if considering a simple model with only two signals that have exactly the same amplitude and an opposite phase. In reality, rays are reflected off of buildings, hills or rocks, "scattering" the original single ray into several and combining those new rays with random phases and amplitudes. By using a statistical model, a more favorable null probability is obtained, mirroring experience and in accordance with the Rayleigh multipath fading prediction. In fact, many experiences in the field demonstrate that in a well-designed simulcast network there is no signal degradation in overlap areas, and there is no need to adjust delays within 15 to 20 kilometers of the cell's radius.

Simulcast Benefits

Digital simulcast systems are the natural evolution of analog systems and allow for a soft migration. In fact, an analog simulcast system can easily be replaced by a digital one without changing frequencies, antennas or sites, allowing the co-existence of analog and digital terminals during the migration period. A well-designed simulcast system not only improves communications but also adds the following benefits.

The Uplink Voting System



Figures courtesy Radio Activity

Better inbound coverage is available through simulcast thanks to the large diversity effect introduced by the voting system.

Maximum spectrum efficiency. Simulcast requires a single channel in an entire area, despite the number of sites. Sometimes, simulcast is the only viable way to build a radio system. For example, it's hard to manage frequencies across borders because of different laws and their application in bordering states. In a multisite trunking system, simulcast solutions best solve frequency allocation problems.

Real-time roaming. Handoff without interruption is possible, including during a communication. Without simulcast, a mobile terminal has to scan all frequencies in the network to find the best radio cell. During scanning, the network connection can get lost, an unacceptable situation in an urban environment where cells are frequently changed.

Better inbound coverage. Thanks to the very large diversity effect introduced by the voting system, inbound coverage improves. The voter selects the best receiving path from all repeaters, burst by burst, providing strong protection from fading holes. Fading is a serious problem in digital communications because a short hole in the streaming can destroy critical information, which is difficult to recover. In fact, an annoying "ciuf-ciuf" noise in analog mode — often heard when a mobile device is moving along a highway, for example — becomes a total loss of communications in digital mode.

Easily expandable coverage area. As in the case of shadowed areas, coverage can expand without the need for new frequencies.

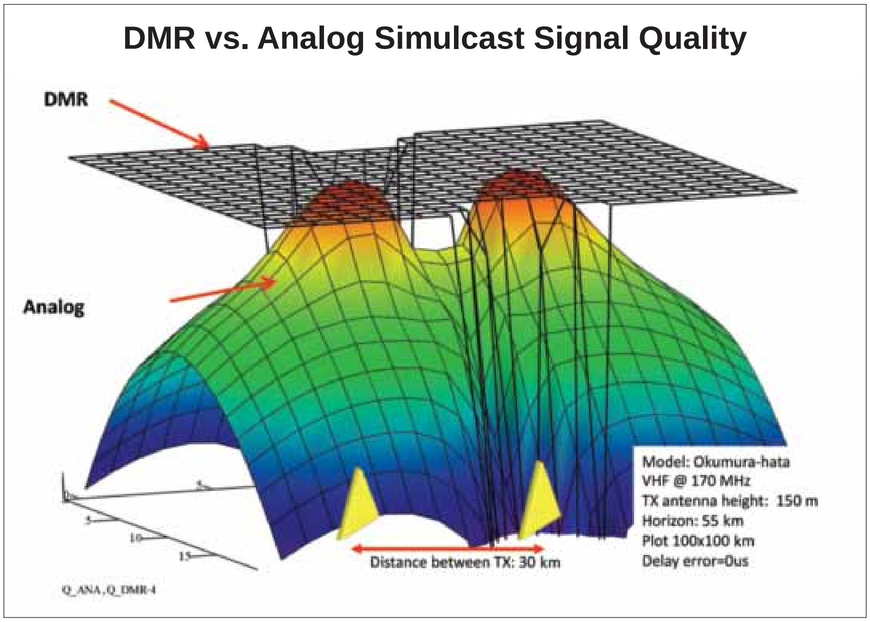
Distributed transmission. Some systems are designed with one high-power TX and some RX-only devices. Simulcast can also distribute a low-powered TX in an RX site. This distributed transmission provides better coverage (in buildings, for example), reduces the interference area outside of coverage, increases system reliability, and reduces dissipation and power supply needs, increasing transmitters' shelf lives.

Simulcast provides insuperable benefits when applied in a trunking system. A multicast trunking system is an insatiable frequency devourer. In fact, a few systems in the same area will use all available spectrum. Alternatively, simulcast trunking mode represents a huge advantage over multicast because it uses the same frequencies on all sites. A common objection is that simulcast trunking doesn't optimize channel usage because it doesn't send a call to just one radio cell. This objection, in many cases, is not a real problem. In fact, in a dispatch/emergency radio system, the majority of communications are talkgroup types, whereas the few private calls are primarily completed with cellular phones. When a talkgroup is requested, the controller has to allocate a channel to each system's site to make sure all group users are served, taking into consideration that users may move across radio cells during the call. The allocated channel broadcasts the same information (call content), but the difference is simulcast uses the same frequency, whereas multicast requires a different frequency for each site.

Therefore, in addition to its other benefits, simulcast trunking provides an enormous gain in spectrum management with a minimal reduction in traffic capability. Continuous handover and roaming during a call are not performed in multicast Digital Mobile Radio (DMR) Tier 3 systems, giving simulcast an edge in such systems.

Digital Simulcast Concepts

Mobile radio communications are quickly moving toward digital technologies, and some new factors irrelevant to analog simulcast mode have to be taken into account. Digital simulcast systems require increased research-and-development efforts

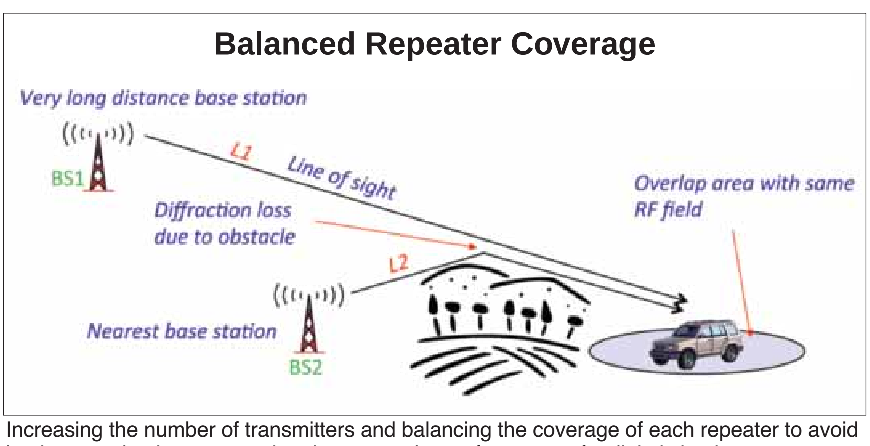


This figure shows signal quality moving in a simulcast environment generated by two digital transmitters 30 kilometers part. The lower plate corresponds to 20 dB of analog SINAD (blue), and the top value corresponds to 40 dB (red). DMR quality is shown by the black grid, characterized by sharp borders instead of a progressive decrease.

compared with analog systems, but by using well-designed base stations, the realization of a professional simulcast network becomes a plug-and-play experience.

The same mechanisms that distort signals in analog communications remain in a digital environment, but others should be considered. The modulation format can be divided into two main types: four frequency shift keying (4FSK), currently the most used for simulcast; and four phase shift keying (4PSK).

4FSK modulation, with some variations, is adopted in NEXEDGE, DMR, Project 25 (P25) Phase 1 and P25 Phase 2 (for mobile only) protocols. This type of modulation is compatible with conventional analog FM and can be considered an analog signal that modulates an FM transmitter by using a base bandwidth from 0 to about 4 kilohertz. Information is contained only in the instant frequency of the RF signal. This allows the use of constant envelope transmitters (Class C, for example) that are simple to design, perform at a low cost and are highly efficient. Unlike analog FM simulcast modulations — in which quality is limited by glitch noise — digital modulations also suffer timing recovery problems and inter-symbol interference (ISI). Because the ISI increases with data rate, a P25 Phase 2 system at 12 kilobits per second (kbps) must be more carefully designed than a DMR or P25 Phase 1 (9.6 kbps) or NEXEDGE (4.8 kbps) system. For a variation of only 2 to 3 decibels (dB) of signal-to-noise ratio near the receiver's threshold, digital communications experience an abrupt break, whereas analog communications perform a smoother degradation. Taking into account the above considerations and adding the propagation effect as well as the carrier on interference (C/I) protection ratio, the figure on Page 20 compares the signal quality of an analog simulcast system with a DMR simulcast system.



Increasing the number of transmitters and balancing the coverage of each repeater to avoid having one dominant transmitter increases the performance of a digital simulcast system.

Moving into the area from one repeater to the other, two opposite properties affect call quality:

- Quality decreases because of the broadcast signals' different arrival times (propagation delay), which produce mismatching;
- Quality increases because of the different signals' relative levels obtained by the co-channel rejection ratio of the FM receiver.

In a simulcast environment, DMR signal quality is strong throughout the area, whereas an analog environment performs at more than 20 dB of SINAD, with no communications outside the coverage area. A P25 Phase 1 modulation performs a bit better than DMR, thanks to the lower compression ratio of the audio, and NEXEDGE should also perform slightly better than DMR because of its lower on-air data rate.

To obtain these results, the matching grade between base stations must be high to confine mismatches in propagation factors. By replacing an existing analog simulcast system with a well-designed DMR system, users can expect to obtain at least the same field quality and probably better quality thanks to the high matching provided by digital transmitters.

With the coverage of each repeater balanced, a simulcast system will perform at its best. In other words, increasing the number of transmitters and avoiding situations in which there is one dominant TX increases performance.

Similar considerations can be extended to a POCSAG system. POCSAG modulation is a simple binary 2FSK that can be viewed as a 4FSK that uses only full-deviation symbols. Unlike the modulations previously described, the transition between symbols approximates a square wave modulation. These fast frequency changes simplify receivers' designs, matching the miniaturization and low power needs. Unfortunately, in a simulcast overlap area, a small delay between transmitting signals can introduce glitch noise during frequency transitions. Fortunately, the POCSAG symbol rate is low enough (512 bits per second to 2.4 kbps) to efficiently remove the glitch noise by using an integration filter. Although simulcast performance somewhat depends on paging terminals' implementation, it is reasonable to expect that because of the low data rates involved, the RF field will affect performance more than the delay spread.

P25 Phase 2 (outbound repeaters only) and TETRA protocols use a modulation based on a 4PSK schema with a gross data rate of 12 and 36 kbps, respectively. This modulation needs linear transmitters because the RF signal doesn't have a constant amplitude. TETRA simulcast does not exist. Conversely, the P25 Phase 2 protocol allows for simulcast, but the higher data rate required in comparison with DMR lowers the acceptable radio cell dimension. In the future, better simulcast performance could be obtained by P25 Phase 2 and TETRA systems if they have delay equalizers in their terminals, as is done on cellular phones.

The design of a digital simulcast repeater requires more accuracy than an analog repeater. Modern radio equipment, based on "soft radio design," removes most of the spread resulting from old, discrete components. As a result, simulcast technology becomes applicable to digital modulations as well, thus increasing overall communications quality while offering outstanding spectrum efficiency. ■

Roberto Marengon is the CEO of Radio Activity, a radio communications engineering firm based in Milan. His career began at Alcatel, where he developed the first Italian 900 MHz cordless telephone. He was the research and development manager of Prod el SpA, formerly Marconi Group, and Selex, now Leonardo, for more than 10 years, developing a new generation of digital signal processing (DSP)-based simulcast networks. In 1998, he formed the engineering company SIEL TRE Srl, focusing on maritime radio applications. Marengon launched Radio Activity in 2003. Email comments to comm@radioactivity-tlc.it.

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