Simulcast P25: Reality and Myth

White Paper

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simoco
connections that count

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The benefits of Simulcast technology are well proven, delivering cost effective wide area coverage, efficient use of frequencies and ease of use for both mobile users and controllers. At the same time, Simulcast has been associated with complexity and a degree of "black art." With the arrival of IP, Simoco has removed much of the confusion surrounding the configuration and management of both analogue and digital Simulcast systems.

However, some manufacturers it seems, have used the shift to P25 digital to introduce new levels of complexity and additional cost that cannot be justified and have overlooked the opportunity to exploit IP as a means of simplifying Simulcast solutions. Andrew Wozencroft, Product Manager and Brian Overton, Systems Engineer, examine the real issues in getting the best performance from Simulcast systems and exploiting the full benefits of an IP infrastructure.

What is Simulcast and what are the Benefits?

When you have a wide area to cover and a limited number of frequencies available it is possible to broadcast the same signal across multiple overlapping sites on the same frequency at exactly the same time. What this means for the user is that they can move between sites without having to worry about changing channels. From the controller or dispatcher's point of view, the transmissions are broadcast from all sites simultaneously, and when receiving, the system automatically selects the site with the strongest received signal.

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As a result, Simulcast gives a more consistently strong signal throughout the coverage area; as you move away from one transmitter you move closer to the next and the connection is maintained.

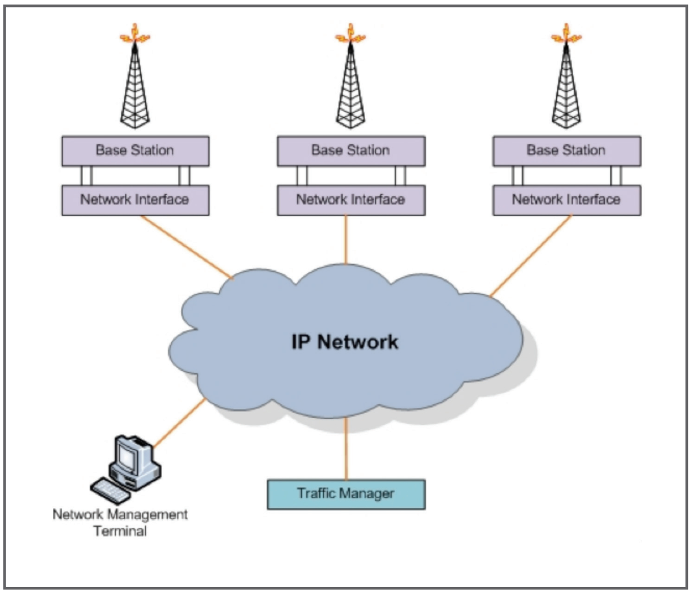
Blanket coverage and mobility are the real benefits of Simulcast and this is especially important for users in public safety and emergency services. For example, when a fire or police commander comes into an area they can immediately pick up the signal and then listen to all conversations as they travel across the coverage area, continuously talking to their teams on the ground as they go.

The way Simulcast achieves this is by a process of "receiver voting". The system determines which radio site is receiving the best signal from the mobile radio and automatically selects that site from which to route the received signal. This process can be undertaken by either measuring the signal level; a method known as RSSI (Received Signal Strength Indication), measuring the quality of the signal (SN or signal to noise voting) or by measuring the Bit Error Rate (BER). At Simoco we use the former as RSSI provides the quickest measurement and therefore the quickest receiver voting. It also performs equally well whether working in digital or analogue modes of operation, unlike BER which is only suitable for digital mode and therefore would introduce yet further delays and require either RSSI or SN in addition to be fully compliant with the P25 standard. Voting is a continuous process and when conducted correctly will result in users being completely unaware of any change in the selected site as they move between sites within the Simulcast network.

Elements of the Simoco Solar P25 Simulcast System

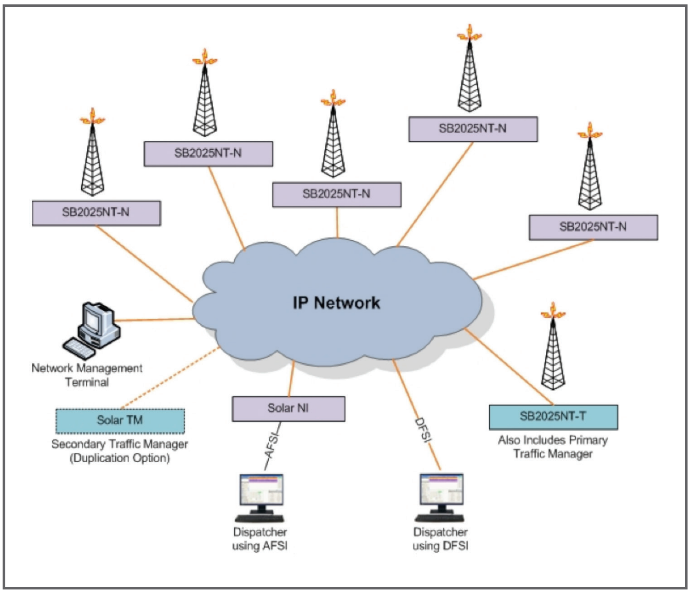
Simoco's Solar P25 Simulcast system is the latest in a long line of Simulcast products from Simoco, originally designed by Dalman Technical Services Ltd who were acquired by Simoco in 2009, having been one of the world leaders in this specialist market. As a result, Simoco not only has the product knowledge, but years of acquired expertise in planning and designing both analogue and P25 digital Simulcast networks around the world.

Three key components make up the system; first the Base Station/Repeater that transmits and receives at the radio site. This is connected to a Solar Network Interface which is incorporated into the Base Station unit. This combined Base Station and Network Interface are together known as the SB2025NT.



The third element is the Solar Traffic Manager. This is an entirely digital device that routes the synchronised P25 signal across the IP network. It also carries out the receiver voting and selects the best signal. The Solar Network Interface uses a process of packet buffering and clock synchronisation in the transmitter path to achieve synchronisation of the transmitted signal. This process is applied in much the same way by the Traffic Manager to the received signal so that that the Traffic Manager always compares like-for-like information from every active site captured at the same moment in time.
The benefit of this is that when a different site is selected midway through a call in order to maintain the best received signal, the change in site does not induce any audible effects to the user. This is true when operating in analogue mode and for systems operating in P25 mode, whilst there may be a slight discernible impact on the audio signal, the Traffic Manager maximises the output of error free data blocks in order to minimise any impact to the user. This process uses bit error rate (BER) and error correction in the Traffic Manager to re-construct the individual data blocks from the raw data that can be received from different sites.

The Traffic Manager has the capability to operate and control up to four P25 channels at the same time. It supports the DFSI (digital fixed station interface) that provides the connection to the P25 control room.
For legacy control systems without a DFSI, a Network Interface per channel is used to provide a 4-wire analogue fixed station interface (AFSI). As the Traffic Manager is a crucial element of the Solar P25 system, a second Traffic Manager can be installed and configured to provide hot-standby with fully automated changeover, giving full system resilience in the event of a fault condition.



Because the entire system is digital and runs on an IP backbone there are a number of distinct benefits over older systems in terms of reducing complexity of set up, operation and cost of ownership. Simoco's IP P25 system affords the ability to remotely configure and maintain network components like Base Stations in the field.
It also means that the network can be easily extended without having to shut the system down or interrupt system operation.

Most importantly an IP backbone allows the use of a reliable and resilient backhaul network, essential when you take into account the critical issues of frequency referencing and signal synchronisation. For example, the use of meshed IP networks will easily remove single points of failure on the backhaul element of the network. Previously, with dedicated point-to-point analogue circuits, the idea of having any form of resilient design through alternate routing was an immensely complex task that few organisations ever contemplated, let alone implemented.

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Special Considerations for Simulcast

In the early days, Simulcast had a reputation for complexity and yet it was a widely used technology. Since the early 90's, Simulcast two way radios have been used by public safety and government agencies in the USA. It is estimated that 30% of public safety agencies currently use Simulcast systems due to a lack of available spectrum and the prohibitive cost of frequency licenses that make other solutions expensive to implement.

Much of the complexity of installation and maintenance has been addressed with the arrival of IP and integration with P25 digital technology which manages many of the "black art" aspects of Simulcast such as signal synchronisation and delay compensation. Being all IP, once audio information has been assembled into IP packets (VoIP) at the start of the process, it is far easier to manage and less prone to errors. Most importantly the integrity of the audio characteristics of the signals being sent to every transmitter site are maintained as they travel across an IP network.

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Overlap Areas are the Benchmark for Quality

It could be argued by some manufacturers that Simulcast by its very nature, introduces radio interference within a system. However, Simoco has employed techniques to provide a resilient and reliable solution that combats interference, making this a moot point when considering the implementation of a Simulcast system. When looking at the common issues surrounding the technology it is important to understand that there are some underlying core principles associated with Simulcast techniques.

From a mobile user's perspective, the effects of Simulcast only come into play when receiving signals from more than one radio site; i.e. when the user is in an "overlap" area. If the mobile user is in an area that is dominated by one radio site the presence of one or more signals from other sites does not really have an impact as the signal used will be that from the dominant site. So it's the overlap areas that are the benchmark for the quality in a Simulcast system.

Whilst areas of signal overlap create challenges in a Simulcast system, the benefits of having signal overlap are twofold. Firstly it helps to provide resilience as there is an increased chance of maintaining radio coverage should a site fail. Secondly, for users on the move, there is improved coverage at the site fringes as signals may be received from other sites since they are also transmitting the same call, so long as the user remains within the overall simulcast network.

Simulcast coverage compares favourably against both conventional and trunked non simulcast systems. In a non Simulcast single site call, whether conventional or trunked, as a user moves into fringe coverage that call will suffer break-up. For a multi site call, break-up will also occur in a conventional system and in the case of a trunked system the radio may attempt to switch channels to try to maintain the connection but this process will also cause an interruption that can be further exacerbated as the user moves around within the fringe area.

Differential Delay

One of the major talking points of Simulcast is caused by the impact of "differential delay". When you are equidistant between two transmitters this is not an issue as the signal takes exactly the same time to reach you from transmitter A as it does from transmitter B. When you start to move towards A and hence away from B, a time difference is introduced by the fact that you are now closer to one transmitter than the other.

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The level of tolerance in terms of differential timing is higher in analogue Simulcast than it is for P25 digital systems. This is because the effect of delay difference is more significant for high frequency signals than at low frequencies since the delay will impact a greater proportion of the waveform. For example; a delay shift of 50 microseconds to an audio tone of 500Hz equates to a phase shift of 9 degrees but to a signal of 2kHz the same delay shift equates to 36 degrees. Since the received signal quality is largely related to the phase difference or phase error between the two signals it can be seen from this simple example that the higher the frequency the greater the impact to received signal quality. As most of the information in analogue voice signals is contained at lower frequencies in and around 1kHz, this only becomes distorted where the timing differential is excessively large. For P25 signals, which occupy a wider bandwidth and can extend from 20Hz to 2.7KHz, the challenge presented by differential delay is far greater than in analogue and drives much debate as to the most effective approach to P25 Simulcast technology.

Antenna Distance: Theoretical Maximum v Real World

A key area of discussion when planning P25 Simulcast networks revolves around the maximum distance between sites and this is related to differential delay. Many in the industry argue, based on a theoretical mathematical formula, that antennas cannot be more the eight miles apart. It is true that when the deferential delay of two signals becomes more than 45-50 microseconds, it becomes almost impossible to recover a received signal of acceptable quality. Radio signals propagate at 5.6 microseconds per mile and that equates to eight miles in 45 microseconds, or 45 microseconds delay per eight miles. But what really counts is the "differential" delay.

To get 45 microseconds difference a user needs to be eight miles distant from one transmitter site with respect to the other; it does not mean that the sites have to be eight miles apart. If a user is close to one site it is most likely that site will be dominant and you will have a good signal quality with no interference regardless of the distance from any other transmitting site. On the other hand, you could be close to a site but environmental factors may screen you to the extent that the site does not have a good signal, in which case signals from sites further than eight miles may well cause interference. So it's not black and white. Other factors come into play. Simoco has deployed many systems where sites extended beyond 8 miles apart and these have proved extremely successful.

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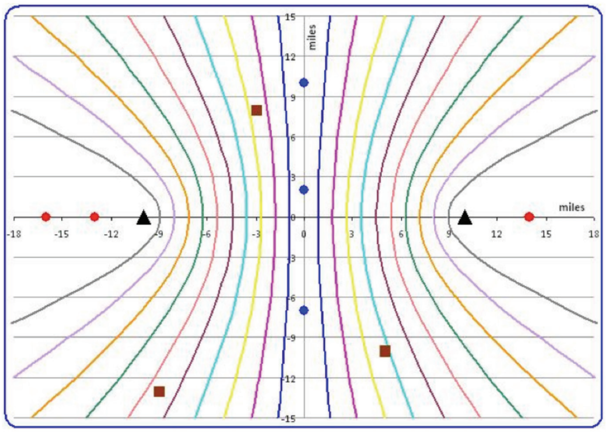

The diagram above shows the differential delay curves or contours spaced at 10 microsecond intervals that are produced by two sites 20 miles apart as indicated by the black triangles. In the centre of the diagram is a vertical line that plots points that are equidistant from each site which in turn means that signals from each site are subject to exactly the same propagation delay. This line therefore represents zero differential delay and three such locations are shown on this line by the blue marker dots. Moving away from this line will result in the signal path lengths becoming more different to each other and so the differential delay will increase. Three examples are shown by the brown square markers which indicate locations where the differential signal delays would be approximately 27, 39 and 56 microseconds respectively moving from the top of the diagram down.

It can be shown that the points of maximum differential delay will only ever lie on the horizontal line that passes directly between the two sites, but always at or beyond either site as indicated by the red marker dots.
This is true because any point off the axis will fall toward a contour line indicating a lesser differential delay.
As stated previously, the points at which maximum differential delay occurs are the very locations where it is most unlikely that signal overlap will be evident, due to one site being dominant.

Modulation: Standard v Linear

The picture with digital Simulcast modulation is somewhat more critical than with analogue. While voice frequencies can vary over a wide range, most information is contained within a relatively narrow bandwidth, whereas with P25 digital voice signals, the data representing the voice occupies a short and fixed space in time. This means that differential delay may not only distort blocks of data, but if the differential is great enough, whole blocks of data can be completely lost. Some vendors have looked at ways to improve the tolerance to the effects of differential delay by introducing non-standard modulation schemes such as linear modulation.

With linear modulation, the transmitter has to be capable of modulating the amplitude of the signal as well as the frequency or phase in order to remain within the P25 standard channel mask and this requires a far more complex circuit. This approach also requires use of a linear power amplifier and inevitably means that the power efficiency of the transmitter is significantly lower than the standard counterpart. Some companies claim that no modification is needed for P25 terminals to receive the signal when linear modulation is used, but the jury is out to some extent on this.

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At Simoco we use a "Non-Linear" C4FM modulation in our P25 Simulcast, which is a common standard for P25 Base Stations and terminal devices. With C4FM there is no need for additional modification to any of the equipment and the adherence to the TIA modulation standard means that Simoco Simulcast systems are optimised for all standard P25 terminals. By adhering to a common standard, interoperability is also guaranteed, enabling greater flexibility across a wide range of hardware and terminal devices.

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Frequency: A Perfect Match?

Frequency matching is another area where some manufacturers overstate the case thereby needlessly adding cost and complexity to the solution. Yes, we need accurate frequency matching but to take this to extremes fails to recognise the realities of how radio signals behave in the real world. Receiving two signals that are perfectly synchronised in frequency when you are static can produce noticeable changes in the received signal strength, depending on whether the signals arrive in or out of phase. The effect on the absolute signal strength is dependent upon the relative levels of the two contributing signals and, in theory, when they are the same level and out of phase then complete cancellation can occur; i.e. they become 'destructive'.

When the signals are in phase they combine to increase the composite signal strength and are then considered to be 'constructive'. At other phase relationships the result may be either an increase or decrease in the composite signal strength.

The following table shows the calculated change in the received signal strength produced by the addition of a second signal at a number of levels relative to the first signal when in and out of phase. The table demonstrates that two signals with a strength level difference of 3dB can result in a variation of composite signal level of around 20dB as the phase of one signal moves relative to the other.

Second carrier relative level	Constructive level (in phase)	Destructive level (out of phase)
0 dB	+6.0 dB	Signal null
-0.5 dB	+5.8 dB	-25 dB
-1.0 dB	+5.5 dB	-19.3 dB
-2.0 dB	+5.1 dB	-18.8 dB
-3.0 dB	+4.6 dB	-15.3 dB
-6.0 dB	+3.5 dB	-6.0 dB
-12 dB	+1.9 dB	-2.5 dB
-20 dB	+0.8 dB	-0.9 dB

When the individual signal levels are high, the drop in composite signal level due to the carriers arriving out of phase is unlikely to produce a complete null in practice but the effect on the received signal level is still very real. At any given location in the signal overlap area the effect on the level of the received signal will remain indefinitely whilst the signals remain synchronised. If the frequencies are not synchronised then the natural variations of the frequencies means that these areas will not be static and this can be beneficial. For this reason many manufacturers, including Simoco, chose not to synchronise transmit frequencies.

We have considered the effect of being stationary in a signal overlap area, but the majority of mobile communications, by their very nature, occur on the move. When you move towards or away from a radio site, that movement effectively produces a shift in signal carrier frequency which is proportional to both speed and absolute carrier frequency, an effect known as Doppler shift.

The following table shows the amount of carrier shift when moving directly towards a site at three different speeds for three different frequencies:

Carrier Freq	Speed	Carrier shift
150 MHz	5 mph	1.11Hz
450 MHz	5 mph	3.33 Hz
900 MHz	5 mph	6.66 Hz
150 MHz	40 mph	8.88 Hz
450 MHz	40 mph	26.6 Hz
900 MHz	40 mph	53.3 Hz
150 MHz	120 mph	26.6 Hz
450 MHz	120 mph	80 Hz
900 MHz	120 mph	160 Hz

If you move towards a site the frequency increases and conversely, when you move away from a site, the frequency decreases. So when we consider the effect of moving through a signal overlap area produced by two sites in Simulcast, the frequency shift will be positive for one site and negative for the other. Travelling in a direct line between those sites will produce a frequency difference of twice the value of the carrier shift as demonstrated in the table above. Travelling in a different direction will reduce the frequency difference effect in proportion to how divergent the direction is from the direct line. In fact, travelling at a bearing of 90° to the direct line between sites will not produce any effect whatsoever. It is clear to see how variable the effect of Doppler shift will be in practice but it remains a very real phenomenon.

For an analogue Simulcast system or a P25 Simulcast system operating in analogue mode, movement in the overlap area will be manifest as a 'beat' or 'flutter' between the two signals that is clearly audible even if the carrier frequencies are absolutely synchronised. However, for P25 Simulcast systems operating in P25 mode the effect of movement induced frequency differences are not directly audible as the audio is contained in the data frames which can cope with the superimposed frequency beat.

Some manufacturers state that a carrier frequency stability of at least 10-10 is the minimum necessary for Simulcast; some state it should be even better than that. Since this former figure will produce an absolute accuracy of 0.045Hz on a carrier frequency of 450MHz, it can be seen that such a high level of accuracy is completely overshadowed when the effects of even a slow rate of movement in a signal overlap area are considered. Let us reiterate, it is the signal overlap areas where the quality of any Simulcast system is determined.

To summarise, matching the carrier frequencies to a very fine level of granularity will add significant cost in return for a marginal, largely theoretical, benefit.

Simple adjustments can make big difference

Simulcast is judged by its performance in the overlap areas and there are a number of ways to optimise performance in these zones. One option is to adjust the signal levels at one or more sites so that the overlap areas change location or alternatively antennas can be changed say from omni-directional antenna to directional, which will again effectively shift the position of the overlap area. This can be useful when the overlap is over a location where one would rather have a dominant antenna. Equally if the overlap in a given location is such that there is a high differential delay, this can be adjusted by introducing small delays in transmission at specific sites in order to optimise the network coverage. This function is performed by the Solar Network Interface and can be carried out remotely over an IP link via the Traffic Manager to a very high degree of accuracy, microsecond by microsecond.

Experience Counts

Simulcast has always been a favoured option for high performance wide area coverage with limited frequencies. The trade-off for this performance is the need to manage the negative aspects of interference in the overlap areas. The development of digital P25 solutions such as the Simoco Solar 25 has brought major advances in minimising the overlap issue. Signal synchronisation and frequency mapping are largely automated while the use of an IP backbone for connecting all network components has led to greater resilience, easier configuration and maintenance with associated cost savings.

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Further Capex and Opex savings can be achieved by challenging some of the perceived truths surrounding P25 Simulcast, such as the need for antennas to be no more than eight miles apart and the requirement for non-standard modulation schemes.

Simoco has a long history of Simulcast installations, a commitment to working to international standards wherever possible and extensive experience in IP based mobile radio networks from the analogue Xfin through to P25 and the DMR based Simoco Xd range. This we believe is the best way to deliver resilient mission critical networks while keeping costs under control.

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About Simoco: Simoco is one of the World's leading radio communications specialists, providing cutting edge Terrestrial Trunked Radio (TETRA), Analogue, Digital Mobile Radio (DMR) and Private Mobile Radio (PMR) products and services to organisations around the globe.

Based in Derby, UK, Simoco, part of the Team Telecom Group, develops radio solutions such as PMR, TETRA, P25 and DMR and works with market leading technologies such as Bluetooth, WiFi, VoiP and DSPs. The company also runs a world-renowned service centre from its offices in Huntingdon, Cambridgeshire, which repairs equipment from current and previous generations of mobile radio.