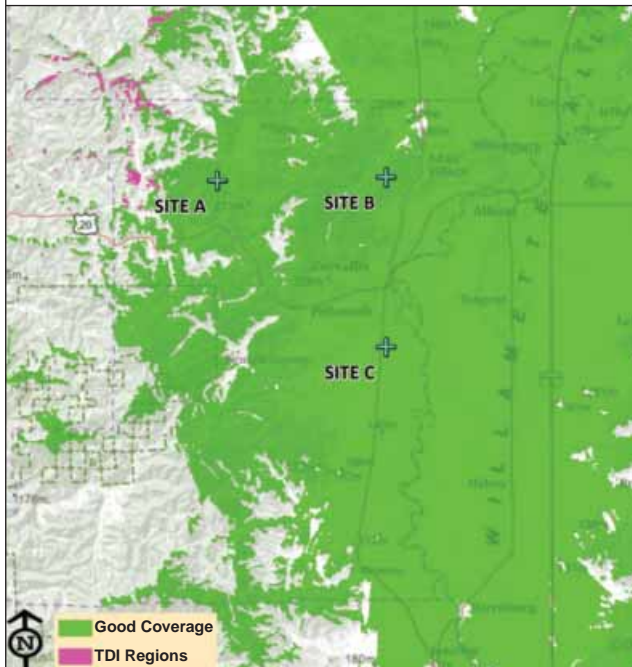
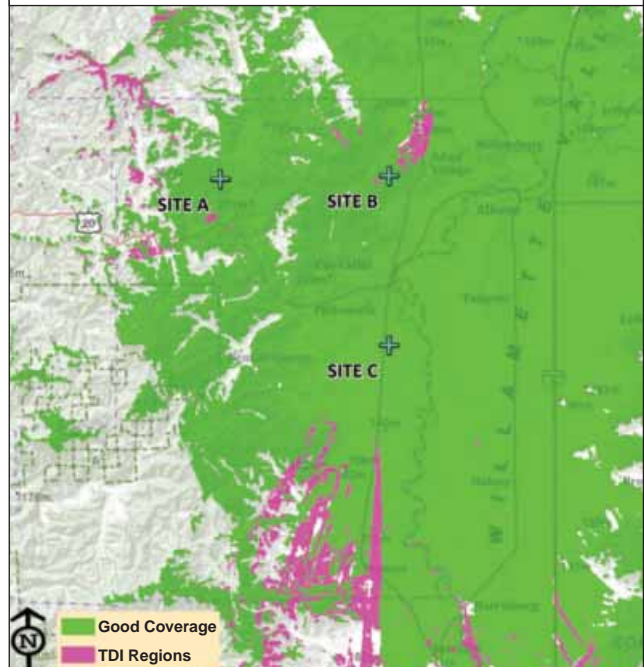


P25 Phase 1 Simulcast Coverage



P25 Phase 2 Simulcast Coverage



A hypothetical three-site simulcast system using real terrain data shows the potential TDI increase when migrating from P25 Phase 1 to Phase 2. Phase 1 has a 60 microsecond acceptable delay spread, and Phase 2 has a 48 microsecond acceptable delay spread.

How Time Delay Interference Affects P25 Coverage

The potential for time delay interference exists when upgrading a Project 25 (P25) simulcast system from Phase 1 to Phase 2.

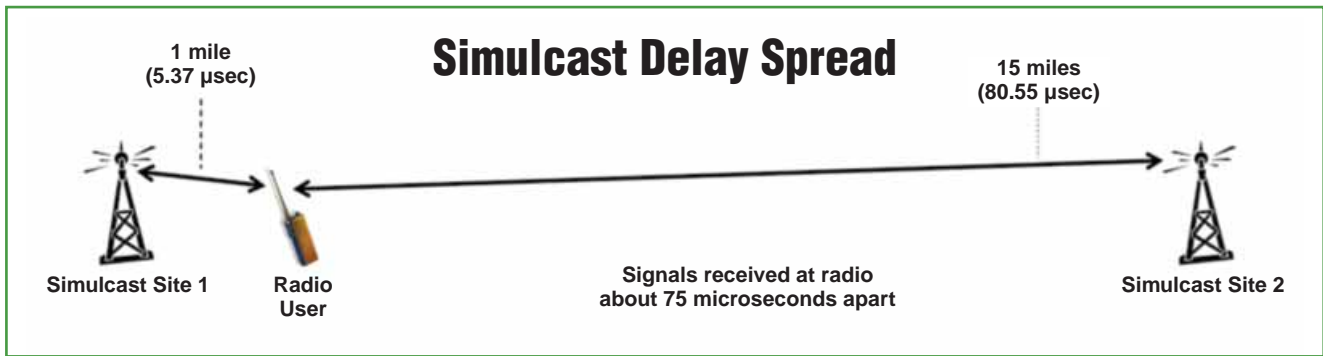
By Adam Nelson and Neil Horden

Are you planning to implement a Project 25 (P25) Phase 2 simulcast system or upgrade your P25 Phase 1 simulcast radio system to Phase 2? Radio system operators have a lot to consider when implementing a new system, and often even more when

upgrading a system. While management of expectations is critical with any new system, many expectations have already been set by the existing system in an upgrade project.

One critical expectation is maintaining the previous network's level of

coverage with the upgraded system. Even though the basic RF coverage of P25 Phase 1 and Phase 2 technologies may not be significantly different, if the system is simulcast, the coverage and performance of the network can be dramatically different. This difference



If the amount of delay is greater than the acceptable limit, TDI could occur, resulting in degraded performance.

can be because of time delay interference (TDI).

Understanding how to evaluate and mitigate TDI is paramount when designing a simulcast system. If TDI is not properly addressed, system performance can be drastically reduced, regardless of how much RF coverage the system provides. Phase 1 and Phase 2 systems use different symbol rates — also called baud or modulation rates — when transmitting information, and therefore have different tolerances when it comes to acceptable delay times.

These differences can manifest in varying degrees from system to system. It's important to accurately predict what the effects of migration will be on your specific system. Adhering to proper system design principles and exercising sound TDI-mitigation techniques can allow radio system operators to upgrade their P25 Phase 1 radio systems to Phase 2 without adversely affecting performance.

What is TDI?

Simulcast radio systems transmit the same frequency or groups of frequencies at multiple radio sites. This is beneficial when frequencies are scarce, because it effectively extends the coverage of a system across a larger geographical area than a single site could cover without requiring additional frequencies. The drawback for a simulcast configuration is that users' radios can be susceptible to TDI. TDI occurs when radio signals from two or more sites arrive at a radio at comparable signal strengths, but significantly far apart in terms of time.

The diagram above demonstrates the phenomenon of TDI. In this case, the radio user is located about 1 mile from the closest simulcast site and about 15 miles from another simulcast site. In theory, the signals from the closer site should be substantially stronger than those coming from the far site. If that is true, then the radio usually can successfully “ignore” the weaker signals coming from the far site, and TDI should not present an issue. However, if the far site is at a high elevation or there are obstructions between the user and the closer site, the signal strengths from the two sites may be comparable at the user's radio. In that case, timing will come into play.

Because radio signals propagate at the speed of light, signals travel around 1 mile every 5.37 millionths of a second (5.37 microseconds). In the diagram, the signals from the two simulcast sites arrive at the user's radio approximately 75 microseconds apart. Depending on the type of simulcast system deployed, this amount of delay could be greater than the acceptable limit, and TDI could occur, resulting in degraded performance, such as distorted reception and/or a loss of part or all of the audio. When designing a simulcast system, the acceptable delay tolerance for the specific simulcast modulation technology usually governs how far apart sites can be located. For example, as a rule of thumb, some use a maximum of 10-mile separation between sites for P25 Phase 1.

P25 Simulcast

For Phase 1 P25 systems, simulcast has traditionally been implemented using one of two methods — linear simulcast or non-linear simulcast. The important difference between these two types of simulcast modulation technologies is that linear modulation provides additional tolerance with regard to the acceptable delay spreads.

Phase 1 systems transmit information at a data rate of 9,600 bits per second. This data rate is often expressed in symbols per second as well, with each symbol composed of two bits (also called a dibit). Therefore, the symbol rate of a Phase 1 P25 system is 4,800 symbols per second. Using this information, we can derive the length of each symbol period (the length of time required to receive one symbol):

$$\text{Symbol Period (Phase 1)} = \frac{1 \text{ second}}{\text{the number of symbols per second}}$$

$$\text{Symbol Period (Phase 1)} = \frac{1 \text{ second}}{4,800 \text{ symbols per second}}$$

$$\text{Symbol Period (Phase 1)} = 0.000208333 \text{ seconds}$$

$$\text{Symbol Period (Phase 1)} = 208.333 \text{ microseconds}$$

The symbol period is directly tied to TDI and acceptable delay spreads, because simulcast radios can properly decode audio from multiple sites only as long as the incoming symbols are not being received at vastly different times. Depending on the manufacturer of the equipment, performance can vary, but in the case of Phase 1 linear simulcast, 60 microseconds is a

Even though the basic RF coverage of P25 Phase 1 and Phase 2 technologies may not be significantly different, if the system is simulcast, the coverage and performance of the network can be dramatically different.

commonly used value for acceptable delay spread.

For P25 Phase 2 systems, the bit rate increases from 9,600 to 12,000 bits per second. In other words, the symbol rate increases from 4,800 symbols per second to 6,000 symbols per second. This increase in transmitted symbols comes at a price, as the symbol period has now decreased, causing the acceptable delay spread to also decrease. Using the same formula from above, we can derive the symbol period for P25 Phase 2 transmissions:

Symbol Period (Phase 2) =
1 second/the number of symbols
per second

Symbol Period (Phase 2) =
1 second/6,000 symbols per second

Symbol Period (Phase 2) =
0.000166667 seconds

Symbol Period (Phase 2) =
166.667 microseconds

Using the P25 Phase 1 symbol period and the commonly acceptable delay spread of 60 microseconds for Phase 1, we can determine what fraction of one symbol is represented by the delay spread value:

Phase 1 Acceptable Delay
Spread = symbol period * fraction
of one symbol

60 microseconds = 208.333 micro-
seconds * fraction of one symbol

0.288 symbols occur during
60 microseconds

Using this coefficient of 0.288
symbols, we can derive a proportion-
ate level of acceptable delay spread
for Phase 2:

Phase 2 Acceptable Delay
Spread = symbol period * 0.288

Phase 2 Acceptable Delay
Spread = 166.667 microseconds *
0.288

Phase 2 Acceptable Delay

Spread = 48 microseconds

As previously noted, the exact tolerance for delay spread varies by manufacturer, but for the purposes of this article, 60 and 48 microseconds are used for P25 Phase 1 and P25 Phase 2, respectively.

Real World Example

The difference of 12 microseconds may not initially seem substantial, but to a radio receiver, it can mean the difference between a usable signal and useless garble. To demonstrate, a hypothetical three-site simulcast system using real terrain data from an area of the state of Oregon exemplifies the potential increase in TDI that can result when migrating from P25 Phase 1 to Phase 2. The state of Oregon is a client of Federal Engineering; however, the system shown in this example is not an existing, planned or proposed system. While the sites used in this case are hypothetical, they are indicative of the mixture of high and low elevation sites often found in simulcast systems in environments with varying terrain.

The first map on Page 27 shows the predicted coverage from a P25 Phase 1 version of the simulcast system. High-quality coverage areas are shown in green. In those areas, a user with a portable radio could expect to receive very good audio. In the pink areas, TDI is predicted. In those areas, signals from two or more sites would be received more than 60 microseconds apart, and at comparable signal strength levels. It is likely that a user in the areas colored pink would experience decreased performance even though they have an acceptable level of signal strength.

The second map on Page 27 shows a P25 Phase 2 version of the same simulcast system. The colors represent

the same level of predicted system quality as the first map. The difference is that the parameter for the acceptable delay spread for deriving TDI was decreased from 60 microseconds to 48 microseconds. The map shows that this decrease in acceptable delay spread results in an increase in TDI, as can be seen in the immediate proximity of Site B, and in a large swath to the south of Site C.

TDI Mitigation

As the maps show, TDI can be present in a variety of places, both at the edges of system coverage and within areas central to the system. But there are a number of ways to mitigate TDI. For instance, the use of directional antennas can allow a system designer to direct the signals from each site toward the exact region that site needs to cover. This helps minimize signal overlap and is the reason that omnidirectional antennas are often discouraged in large, wide-area simulcast systems.

Other mitigation techniques include adjusting the radiated power, either transmitter output power or effective radiated power (ERP), from a site to control its overall range. When accomplished properly, this can reduce that site's effect as an interferer to other sites in the simulcast system. Additionally, choosing a specific antenna with a tightly controlled vertical pattern or lowering an antenna's mounting height or the position on a tower, can also assist in reducing its interfering effect without undue coverage reduction.

The mitigation techniques described all have one factor in common: They modify the coverage from one or multiple sites to try to reduce the potential for TDI. However, these methods may not be feasible in all systems. Another technique frequently

employed by system designers is the use of staggered launch delays between the sites. Staggering launch delays involves modifying the time when a particular site transmits its signal relative to the other sites. This effectively shifts the predicted TDI locations within the coverage area. The goal is to shift the area with TDI outside the intended service area of the system. Designing a simulcast system with staggered launch delays is a complex process, usually involving iterative calculations attempting to determine the optimum combination of launch delays for the various sites.

Upgrading a P25 simulcast system from Phase 1 to Phase 2 doesn't necessarily mean that TDI will limit the system's coverage. However, it is

vital to understand that the potential for TDI exists. It is equally important to assess this risk through coverage and interference analyses in the design of the system. In most cases TDI can be minimized, and in some cases it can be eliminated. Other systems may require mitigation methods, such as using antenna design and launch timing to move the area of TDI outside the critical coverage areas. In all cases, expectations have to be managed and the system must be optimized prior to the migration of users onto the system. ■

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