Navigating the P25 Maze

Which system is right for me?

White Paper

CONTENTS

EXECUTIVE SUMMARY

P25 radio networks come in two basic system types: conventional and trunked. Either type can optionally make use of simulcast. This white paper aims to assist those who need to make basic choices about the sort of network they want.

Conventional networks are suitable for small to medium installations. Their big advantage is that they can be dual mode, supporting analog radios and allowing a phased migration to digital. Because signaling is digital, they also have many features traditionally associated with trunking.

Trunked networks provide additional intelligence, through the addition of trunking controllers. These control access to the network and enable more efficient channel use. Trunked networks can be interconnected to provide state-wide or even nation-wide coverage.

Simulcast means that multiple repeaters use the same transmit frequency. Both trunked and conventional networks can use simulcast. Many organizations need simulcast, because of the shortage of spectrum. Simulcast can be used in part or all of a network.

Choosing a conventional network does not prevent a later migration to trunked; most vendors' equipment allows trunking controllers to be added later, turning the network from conventional into trunked.

There are advantages and limitations to all P25 system types and the key to navigating through the P25 system maze is to understand clearly what your organization needs from a radio communications system and what your business case is. An important stage of this decision process is partnering with a vendor who understands your needs and can help you decide on the right option for you.

INTRODUCTION

P25 is an open standard designed by public safety for public safety. Accordingly, it is the radio network standard of choice for public safety in North America and in many other parts of the world. Increasingly, it is also a real option for organizations involved in other activities such as electricity distribution, light rail transport, border security and airport immigration and customs.

P25 has a maze of different features and capabilities and these vary according to system type. Finding your way through the maze and deciding on the right system type can be a challenge.

For some, the choice of P25 system type will be obvious:

▶ **Trunked** if they need to cover a very wide area, have a large number of users, or want to interconnect with neighboring networks to provide system-level interoperability.

▶ **Conventional** if they require a small system, with only a few channels at any one site.

▶ If spectrum is limited or expensive, part or all of the network might need to be **simulcast.**

Others may need to carefully understand the differences and explore the features and benefits of each system type, so that they can make a good decision. This white paper aims to provide guidance in this situation.

P25 radio networks bring many benefits, including the following:

▸ **Vendor choice:** An open, non-proprietary and continually evolving standard, giving buyers a choice of vendor.

▸ **A P25 Compliance Assessment Program (P25 CAP):** This gives purchasers assurance that P25 equipment is interoperable, conforms to the P25 standards, and meets performance requirements. Look for the Suppliers Declaration of Compliance (SDoC).

▸ **Secure communications:** Digital encryption using the DES or AES encryption standards with optional Over-The-Air Rekeying (OTAR), which means that keys can be updated without returning radios to base.

▸ **IP-based infrastructure:** This is packet-switched and allows the use of cost-effective commercial off-the-shelf equipment. (Many P25 vendors now supply equipment with built-in IP support.)

▸ **Digital voice quality.**

This white paper first explains the basics of each P25 system type clearly and simply, pointing out the key points of difference. It then looks objectively at each type, listing not only the benefits, but also alerting you to possible limitations, which are often obscured by marketing hype. Tait offers all the described P25 system types, so has no vested interest in promoting one against the other.

P25 CONVENTIONAL NETWORKS

P25 conventional networks require less infrastructure equipment and so have a lower level of complexity. Calls are quick to set up and operation can be very like the 'all-informed' character of analog conventional networks, if all radios in the fleet are given the same group ID. Digital design makes the network even simpler to program and allows it to support a range of call types and supplementary services traditionally associated with trunking alone: group and individual calls, caller ID, call alert, discreet listening, radio check, status messaging and status requests, monitoring a radio unit, and inhibiting stolen radios. Dual mode allows interoperability with analog users and enables a staged transition to digital. It is also easier for conventional users to switch to direct mode for peer-to-peer communications that bypass the repeater; all they need to do is press a function key.

Calling a network 'conventional' only tells you that it is not trunked. Conventional networks can be analog or digital or both. They could be anything from a single base station/repeater to a wide area network with multiple base station/repeaters at each site and several dispatch positions as well.

The following sections describe in detail how conventional networks operate, focusing particularly on areas that differ from trunking.

DUAL MODE

P25 conventional networks are usually capable of handling both analog and digital calls (dual mode). There can be a mixture of analog and digital channels, or each channel can be configured to handle both analog and digital calls. P25 radios are required to support dual mode, which means they can make calls to and receive calls from analog radios. Dual mode makes it possible for a network to migrate step-by-step from legacy analog to dual mode and then to digital only. It also supports interoperability with users such as firefighters who may want to continue using analog.

WIDE AREA COVERAGE

A conventional network can provide wide area coverage. Base stations at each site listen on the same frequency for calls from a radio and pass any voice they receive to the comparator at the prime site. This compares the quality of the received voice streams, selects the best stream and then forwards it to the dispatcher and sends it back to the base stations for repeating. (TaitNet conventional P25 networks do not use comparators; their function is built into the TB9100 base station or trunked analog gateway.)

Base Station
Site 2

Base Station
Site 3

IP–based
Infrastructure

Prime Site

Comparator

Base Station

Dispatch
Console
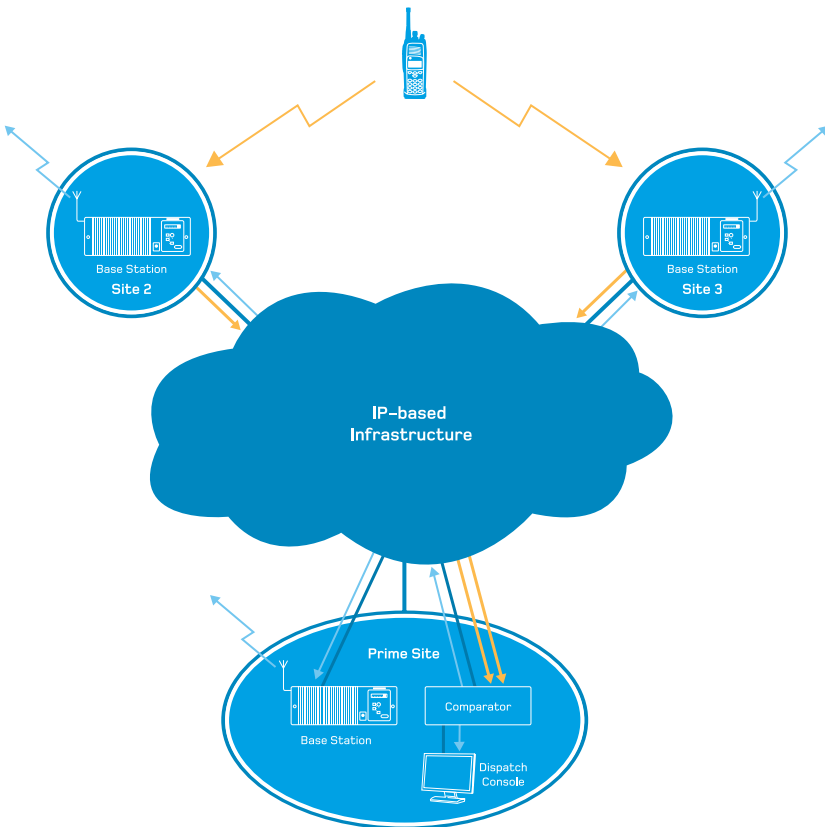
Conventional three-site network showing equipment for one channel

Traditionally, networks used circuit-switching equipment to route the voice streams to their destinations, but modern P25 conventional networks use an IP backbone. This is packet-switched and uses commercial off-the-shelf equipment such as routers and switches.

RADIO OPERATION

To make a call on a conventional P25 network, you simply press the Press-to-Talk button (PTT) and start talking. To talk to a different group, you first select a different channel, for example by turning a knob.

Making individual calls is also possible. As a digital standard, P25 supports them without requiring the use of special protocols such as MDC1200 or Selcall. You dial the number and press PTT. Only the radio you called unmutes to the signal.

MOVING AROUND THE NETWORK

As a radio moves around the coverage area of the network, it must continue to be able to receive signal. In a conventional network, this can be achieved in a variety of different ways.

▶ A single powerful transmitter at a high site, with additional receivers at fill-in sites to compensate for the transmit power imbalance between the base station and the radios.

▶ **Simulcast:** All transmitters transmit at the same frequency.

▶ **Transmitter steering:** All transmitters are set to the same frequency, but only the transmitter closest to the talking radio transmits. Transmitter steering can be automated (the network chooses the transmitter at the site with the best received signal) or manual (the dispatcher selects the transmitter).

▶ **Scanning and voting:** In networks that use scanning and voting, the base transmitters transmit on different frequencies. When subscriber radios are idle, they scan the base transmit frequencies. As soon as they detect signal (the beginning of each call consists of a preamble), they scan and vote, selecting the best signal in time for the beginning of voice.

CHANNEL ASSIGNMENT

The network needs to make channels (frequency pairs) available for calls. Conventional networks generally assign channels to talk-groups. For example:

Channel 1: Fire   Channel 2: Police   Channel 3: EMS

Channels are assigned to talk-groups in a conventional network

Alternatively, several groups can share a single channel. Radios only unmute to calls addressed to their talk-group. Sharing a channel really only works if channel loading is light. Otherwise users too often find that their channel is busy, in use by another group.

NETWORK ACCESS

Conventional P25 networks do not control user access. Anyone can use the services of the network, provided their radio is configured with the correct Network Access Code (NAC). NACs can also be used to partition different user groups on the same channel, so that each does not hear the other.

HIGH AVAILABILITY

Radio communications are often mission-critical. Equipment failures are unavoidable, but networks can be designed to minimize the effect of such failures and to ensure that the network has high availability. Conventional networks can be designed so that there is an alternate channel that users can switch to if their channel fails. Users can also change to direct mode, communicating directly with each other and not via a repeater, but this reduces the effective coverage area.

DISPATCH SUPPORT

Conventional P25 networks support line-connected dispatch equipment. Legacy analog dispatch equipment can be connected via a gateway that converts between analog voice with legacy signaling protocols and P25 digitized voice and signaling. Digital dispatch equipment can connect to conventional P25 networks using the P25 DFSI interface.
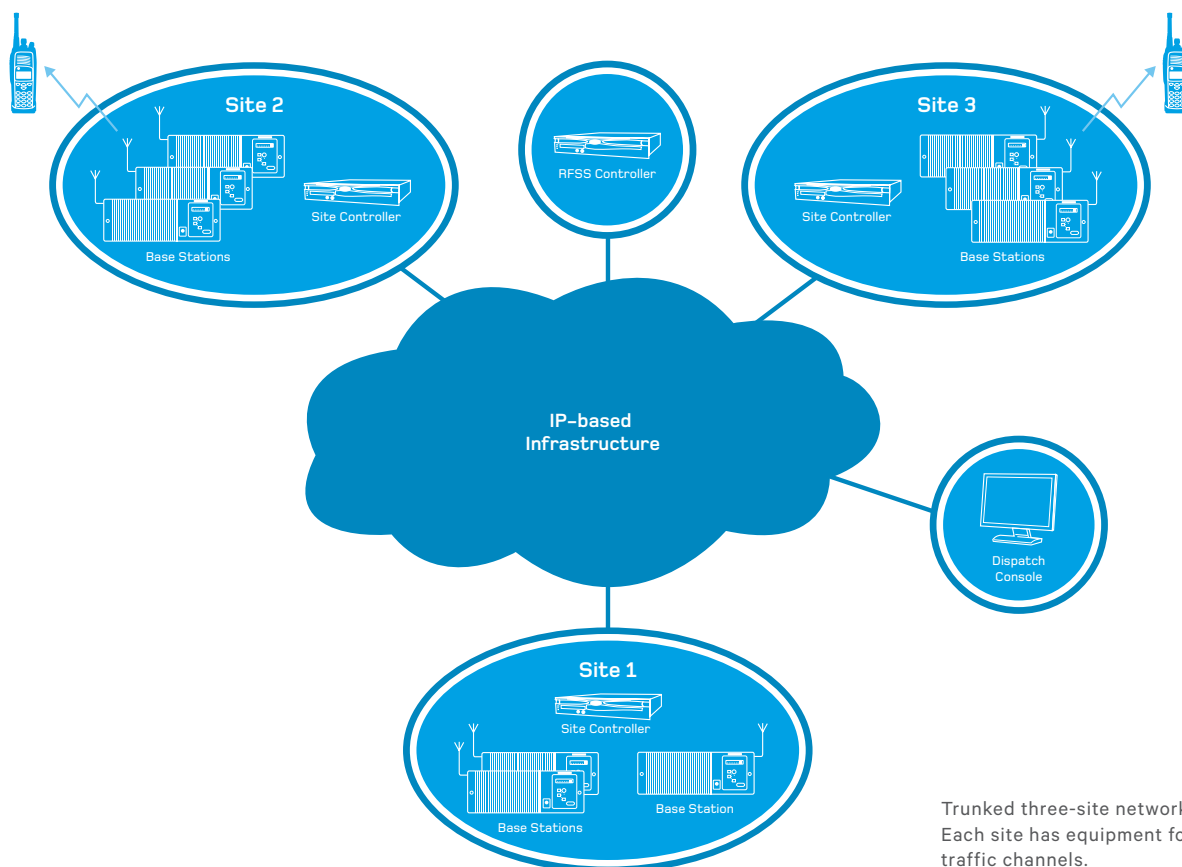
P25 TRUNKED NETWORKS

Trunked networks optimize channel use, so that fewer base stations are needed to support a given number of radios. They are more scalable. Sites and channels can be added without needing to call radios in for re-programming. The ability to queue calls means that trunked networks handle high traffic loads better. Trunking controllers restrict access to the network, increasing security, and monitor network operation, enabling automatic recovery from fault conditions.

Trunked networks get their name from the telephone world. Traditionally, the telephone lines connecting two cities are referred to as trunked lines, because they are bundled together to form a single thick stem. By contrast, the local loop lines going to each house spread out like the branches of a tree.

Trunked lines differ from local loop lines in that they do not belong to one telephone user, but are assigned as needed. Trunked radio networks assign RF channels in the same way.

Trunked networks require additional infrastructure equipment and the radios that use them must be trunking-capable. Trunking controllers give the network its intelligence, checking whether a radio is permitted to make a call and assigning a

free channel. Generally, there is an overall controller and a site controller for each site in the network. The radios receive messages from the site controller. When they are told which channel to use for a call, they quickly tune to its frequencies.

Trunked three-site network. Each site has equipment for two traffic channels.

In trunked networks, one base station at each site provides the control channel, which transmits all the time. Radios register with a control channel and listen to the messages from the site controller that it sends. When the radio user presses PTT to make a call, the radio sends a request to the control channel, which gives the radios the necessary instructions. The other base stations at each site are traffic channels, available for assigning to voice or data calls.

Trunking provides a richer feature set, because of the role played by trunking controllers. For example, emergency call behavior is configurable; if all channels are busy, an emergency call can immediately pre-empt an existing call, or it can simply go to the top of the queue, becoming the first call to be set up once a channel is free.

The following sections describe in detail how trunked networks operate, focusing particularly on areas that differ from conventional.

RADIO OPERATION

Operating a radio is different on a trunked network. To make a group call, you press PTT and then wait for confirmation beeps before starting to talk. Pressing PTT sends a call request. The network checks that the radio is authorized to make the call, assigns the traffic channel(s) required, and then tells the calling and called radios to go to the channel. All this happens before the confirmation beeps.

To make an individual call, you select the individual from a list or dial the number and then you wait for the called party to answer, as in a telephone call.

If the network is busy and there are no free traffic channels, it queues the call and lets you know when a traffic channel has become available.

If you migrate from a conventional to a trunked network (or vice versa), radio users will need re-training and some time to become accustomed to the differences.

MOVING AROUND THE NETWORK

When a radio is turned on or moves to a different site, it tells the network which group it belongs to. The network uses this information to track the location of talk-group members, so that a site only assigns a channel for a call if members of that talk-group are registered at it.

Trunking intelligence also facilitates the handover from one site to another. The control channel sends information to radios about the current control channels (the adjacent channel list). When the radio is not in a call, it scans the frequencies in its channel list and votes on their quality. Because it has information from the network, the radio only needs to check the transmit frequencies of the current control channels. If a significantly better control channel is found, the radio registers with it. All this occurs automatically, requiring no user intervention.

CHANNEL ASSIGNMENT

Channels are dynamically assigned; the trunking controller rotates through the list of available traffic channels, assigning the next call to the next channel on the list. A channel is therefore not used by one talk-group exclusively.
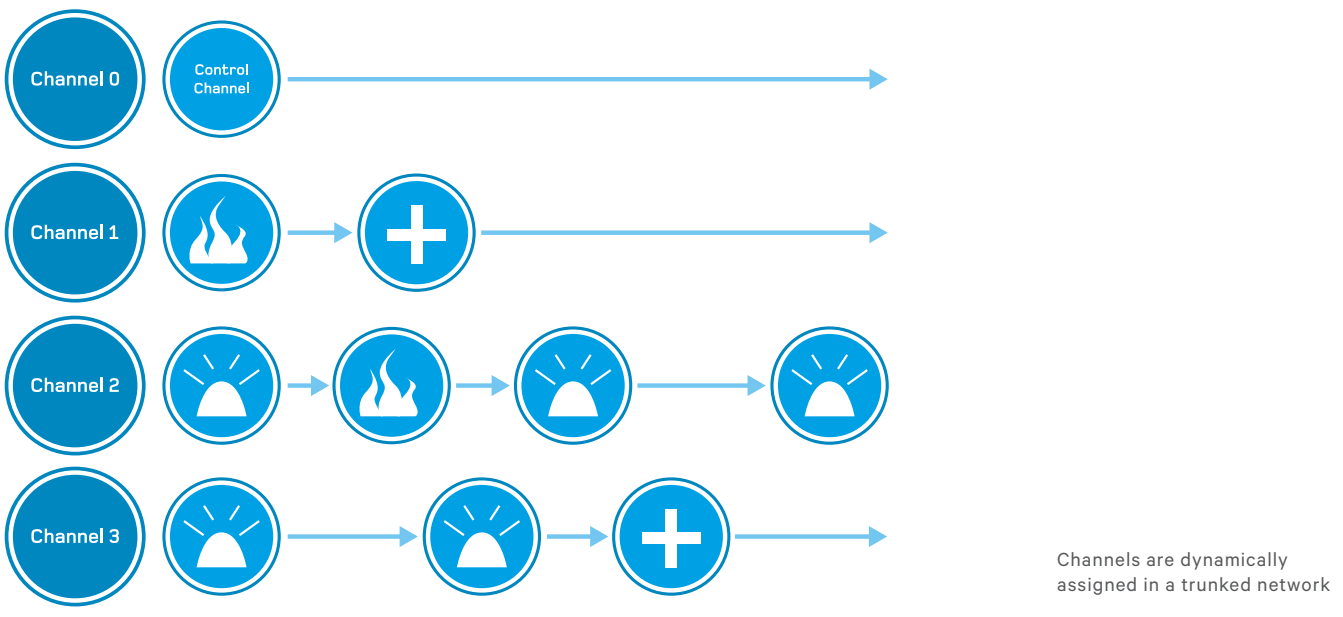
Channels are dynamically assigned in a trunked network

NETWORK ACCESS

P25 trunked networks control radio access to network services. Radios must be known to the network before they can register and request services. The trunking controller has a database listing all the radios permitted to use the network and indicating which services they may use.

HIGH AVAILABILITY

Radio communications are often mission-critical. Equipment failures are unavoidable, but networks can be designed to minimize the effect of such failures and to ensure that the network has high availability. Trunked networks have a range of options for ensuring the high availability of radio communications.

▶ If a traffic channel fails, the site controller does not use it. The capacity of the site is reduced by one channel.

▶ If a control channel fails, the site controller assigns its role to an existing traffic channel. The capacity of the site is reduced by one channel.

▶ Single points of failure can be reduced or eliminated by providing redundant controllers and network links.

▶ An optional failsoft mode can be set up. If the site controller or its link fails, the control channel can continue to operate as a failsoft channel, providing one channel to users at the site and a line connection to dispatch equipment. Radios go into failsoft mode and use the failsoft channel in a conventional way. When the controller or its link are restored, the radios automatically resume trunked operation.

▶ If there is a catastrophic failure of the network, users can switch to a channel that is configured for direct mode. They then communicate directly with one another and not via the network. This reduces the effective coverage area.

OPERATIONAL FLEXIBILITY

Trunked networks have greater operational flexibility. They don't need re-configuring as operational requirements change. For conventional networks, you need to decide for each site which user groups will be provisioned with a channel. As user group needs change, channels and the radios that use them need re-configuring. With trunked networks, the sites automatically provide channels only for those user groups that are working within their coverage area.

DISPATCH SUPPORT

Trunked P25 networks support line-connected dispatch equipment. Legacy analog dispatch equipment can be connected via a gateway that converts between analog voice with legacy signaling protocols and P25 digitized voice and signaling using the CSSI interface to connect with one or more P25 trunked networks. Digital dispatch equipment can connect to trunked P25 networks directly using the P25 CSSI interface.

INTERCONNECTING NETWORKS

The P25 standards define how P25 trunked networks can be interconnected, providing state-wide or even nation-wide coverage. These networks can even be from different vendors, as long as they conform to the P25 ISSI interface.

P25 SIMULCAST

Simulcast (simultaneous broadcasting) is the simultaneous transmitting by multiple base station/repeaters of the same signal on the same frequency. This makes it possible to extend the coverage of a single frequency pair to a very wide area. Using the very exact timing signal provided by GPS receivers located at each site, simulcast transmitters transmit together at a precisely defined time.

In some areas of the network, one transmitter's signal is much stronger, capturing the radio's receiver so that other signals have no effect. In other areas, the radio will receive signals of a similar strength from two or more transmitters. In these overlap areas, the signals may add together, making them stronger, or they may interfere with each other, causing a gap in coverage. Careful network design, coverage modeling and configuration adjustments are needed to minimize this interference and ensure good reception in these overlap areas.

While adding simulcast base stations widens the coverage area, it does not increase call capacity. A set of base stations transmitting on a single frequency can only handle one conversation, no matter how many of them there are.

Many organizations find that they need simulcast because there just aren't enough frequency licenses available to provide the necessary coverage and channel capacity. For example, a 7-site, 4-channel network needs 28 frequency pairs. (This number could be reduced somewhat, through re-use of the same frequency pair, but only for base stations that are so far apart from each other that there is no overlap in coverage.) The equivalent simulcast network needs only four frequency pairs.

In a conventional network, adding simulcast makes radio operation the simplest of all. Because the transmitters on a channel all transmit at the same frequency, there is no need for the user or the radio to do anything to move to a better transmitter. The radios in a talk-group always listen to the one frequency, regardless of their location. Radio users would only change channel if they need to communicate with a different talk-group.

In a trunked network, simulcast can improve in-building coverage. It also enables a single site controller to provide wide area coverage; the control channel and each traffic channel each consist of multiple synchronized transmitters, one at each subsite (radio area).

## ADVANTAGES AND LIMITATIONS

CONVENTIONAL NETWORKS

Advantages

▶ **Staged migration.** Dual mode allows a staged migration to digital. P25 radios can operate in analog mode on legacy infrastructure and legacy analog radios can operate on P25 conventional networks. This maximizes the value obtained from existing equipment, spreads the cost of moving to a new network, and avoids the expense and risk of a fork-lift replacement. Note that this is not available in simulcast.

▶ **Built-in interoperability.** Dual mode enables interoperability with other agencies that are still analog. This type of interoperability carries no extra cost and requires no special system design features. Users simply switch to an interoperability channel, which is analog and can be used by both analog and digital P25 radios.

▶ **Quick call setup.** Call setup time is under 200 ms, which is barely noticeable. There is no need to wait for the trunked network to validate the request and tell the radio what frequency to go to, and for the radio to tune to the channel, before beginning to talk.

▶ **Simpler network design.** Having no trunking controllers means lower infrastructure costs, at least for smaller networks.

▶ **Lower power consumption.** Having no control channels and no trunking controllers generally means less equipment and lower power consumption on high sites.

Limitations

▶ **Inefficient channel use.** User groups either must have a channel to themselves, or share a channel with other groups. If there are more than four channels at a site, conventional networks are less efficient in their use of channel resources. It can easily happen that one channel is overloaded, while other channels are unused. This is like a bank, where each teller can only handle one transaction type.

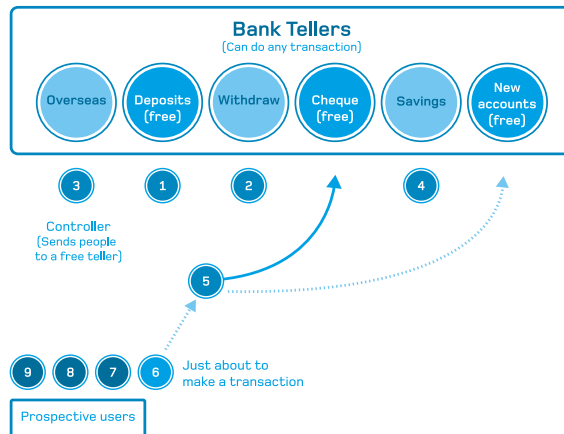Example of how channel use in a conventional network can be inefficient
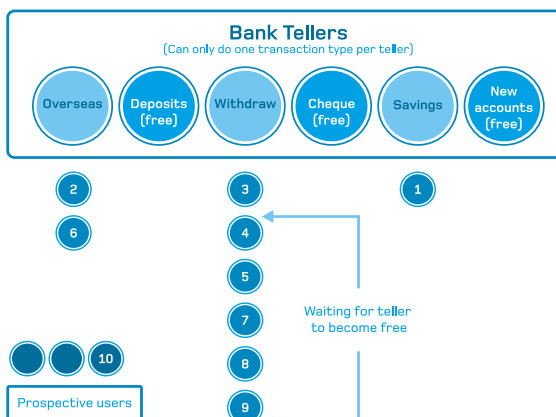
▶ **Busy channels.** If the channel is busy, the caller receives no indication of this. There is also no indication when the channel comes free. The caller can only try again randomly, to see if a call can be made.

TRUNKED NETWORKS

Advantages

▶ **Efficient channel use.** Trunking intelligence balances the load on the network, spreading the load equally over the available channels. This makes for more efficient channel use, provided there are more than four channels. It is like a bank, where someone directs customers to the first free teller. Moreover, a site is only involved in a group call if a radio from the group is registered there. Otherwise, channels at the site are all available for other calls.

Example of efficient channel use in a trunked network

Bank Tellers
(Can do any transaction)

Overseas | Deposits (free) | Withdraw | Cheque (free) | Savings | New accounts (free)

3 | 1 | 2 | | 4

Controller
(Sends people to a free teller)

5

9 8 7 6 | Just about to make a transaction

Prospective users

▶ **Queueing.** If the network is busy when a call is attempted, it queues the call. When a channel comes free, the radio indicates this to the user. The caller can press PTT to make the call.

▶ **Very wide area capability.** Radios can roam onto other networks (RFSSs) and still communicate with the home dispatcher and with their group. To support this, the networks need ISSI gateways and both networks and radios must be suitably configured.

Limitations

▶ **Different radio behavior.** Radio users need to adjust to different way of operating, if they are used to a conventional network.

▶ **Longer call setup time.** After pressing PTT, users need to wait for go-ahead beeps before starting to talk. Call setup time can be up to 900 ms.

▶ **Additional cost.** Trunking controllers increase the cost of the network. High availability requirements often mean that duplicate equipment must be purchased, in order to avoid a single point of failure. These increases can be offset by savings through more efficient use of channels.

▸ **Inefficient for small networks.** The network must use one channel at each site as the control channel. If the anticipated network loading only requires 1-3 simultaneous conversations, trunking will be less efficient in its channel use. Some vendors can supply composite channels (channels that can be used as both a control channel and a traffic channel). These mitigate but do not eliminate this limitation. Even if the coverage area is small, an expensive RFSS controller is still needed.

SIMULCAST

While spectrum efficiency is the primary reason for choosing simulcast, there are some benefits along with the intrinsic limitations.

Advantages

▸ **Seamless roaming.** On a conventional simulcast network, radio users can migrate anywhere within the coverage of multiple transmitters, as they all operate on the same frequency. There is no need to change channel manually. The radio does not need to scan and vote, which increases call setup time and sometimes results in late entry to calls.

▸ **Better in-building coverage.** In overlap areas, the network provides signal from multiple directions. This can improve coverage within buildings and in high-rise areas.

Limitations

▸ **Additional cost.** Each site must have a GPS receiver and equipment to provide a GPS-derived timing signal.

▸ **Coverage issues.** Simulcast requires careful network design and configuration to reduce or eliminate overlap areas with too much delay spread. Additional towers may need to be installed and signal quality may still be suboptimal in some places.

▸ **No dual mode.** Conventional simulcast networks do not support dual mode.

SUMMARY

The following table summarizes the features and limitations of each system type. Where simulcast has no effect on a feature, the table displays 'No change.'

FEATURE	CONVENTIONAL	TRUNKED	CONVENTIONAL SIMULCAST	TRUNKED SIMULCAST
Network access	Uncontrolled	Controlled	No change	No change
Dual mode	Yes	No	No	No
Channel efficiency	More efficient if <4 channels	More efficient if >4 channels	No change	No change
Spectrum efficiency	Low	Medium*	High	High
Call setup time	Begin talking immediately	Wait for go-ahead beeps	Slightly longer than conventional	Slightly longer than trunked
Roaming	Transmitter steering, manual switching, or scan/vote	Almost seamless. Site tells radio about adjacent sites. Radio automatically scans and votes control channels when idle.	Seamless	Seamless
Queuing	No	Yes	No change	No change
Power consumption	Basic	Additional requirements	Little change	Little change

*Trunking's higher channel efficiency means that fewer channels are required.

CONCLUSION

P25 networks come in different flavors and this white paper has described them and explained their advantages and limitations. Provided you clearly understand what your organization needs from a radio communications system and what the business case for it is, this white paper should have helped you to find your way through the P25 maze and decide on the right option for you.

TAIT COMMUNICATIONS

Tait Communications is a global leader in designing and delivering radio solutions which are the right fit for a variety of industries including; public safety agencies, government services, utilities and urban transport providers.

MORE INFORMATION

For more information on TaitNet P25 network options: conventional, trunked and simulcast, please contact your nearest Tait dealer.

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