DISTRIBUTED LOGIC TRUNKED RADIO SYSTEMS

KENWOOD

General:

This paper has two purposes: First, it describes the fundamental concepts of modern analog Trunked Radio Systems, their features and differences compared to conventional radio systems and it provides some guidelines for maximizing a trunked radio system's performance. This fundamental information is intended for non-radio professionals, those persons with administrative or technical management backgrounds.

Second, this paper goes into detail explaining the functional and technical aspects of the Distributed Logic approach used by Kenwood in designing and constructing trunked radio systems. This detailed technical information, specifically intended for radio professionals, describes the system logic and the operation of the trunked system and subscriber units.

Many system-specific features are available to customize a system or to create wide area networks. For additional information or system design assistance, call Kenwood U.S.A. Corp. – Communications Division at 1-800-TRUNKING (or 678-474-4700).

Trunked Radio Systems, an Overview:

In _conventional_ radio systems, a group of mobiles occupies a single radio channel. When units need to communicate, this single channel carries their traffic. This channel usually remains idle for many hours each day with only a few minutes of actual traffic time.

To use this single channel more efficiently, unrelated groups of users often share a conventional channel. Although several groups of users can usually co-exist on the same channel, as their numbers increase so do interference and contention between units. In practice, only a small number of user groups can be assigned to each conventional channel before contention renders the channel useless. Since each channel still has significant idle periods, a conventional radio system is a very inefficient use of the channel's possible airtime, even when heavily loaded. There is no privacy in conventional radio systems, since all users can hear all others as they monitor the channel for traffic already in progress before transmitting (an FCC requirement intended to minimize contention).

To improve spectral efficiency by maximizing the use of available airtime, a means of coordinating many users onto a group of channels was developed. These users operate on a non-interfering basis in a 'trunked' architecture similar in concept to the Public Switched Telephone Network (PSTN). Using this concept, a mobile can be transparently assigned to any channel in a pool of idle channels for his traffic, remaining free of interference or contention with other users. This coordination of frequency-agile mobiles and intelligent repeater stations is a Trunked Radio System.

The trunking concept is based on the probability that in a multi-channel system not all channels will be in use at the same time.....and not all users will need to be transmitting at the same time. A mobile unit that is automatically informed of available repeaters (or informed of which repeater is calling), then automatically switched to that channel, has a much greater chance of obtaining a channel when needed (a greatly reduced probability of contention or call blocking). In this manner, a limited number of trunk channels can accommodate a very large number of end users. Trunking allows easier communication flow for the user while greatly increasing channel efficiency over conventional systems.

One approach to trunking uses existing conventional repeaters. These systems' control logic depends on the subscriber units themselves, with the mobiles constantly scanning conventional repeaters for available traffic channels or for inbound calls. These systems

are defined as 'de-centralized trunking' and are characterized by the lack of a requirement for all repeaters to be co-located, by compromises in features, loading capabilities and speed as well as by their lower cost. Feature sets and capabilities are largely determined by aftermarket boards added to the subscriber units. This can create model-specific or aftermarket board-specific risks to the system's configuration and to the system's overall performance characteristics. Scan-based trunking systems are widely used overseas where limited resources may be the primary determining factor of a system's performance characteristics. Scan-based de-centralized trunking approaches are outside the scope of this paper.

There are two basic 'centralized trunking' system architectures, those using high speed data on a dedicated control channel and those using low speed sub-audible data on all system channels to assign their subscriber units to available traffic channels. Both types can accommodate normal two-way radio traffic as well as interconnection between subscriber units and the Public Switched Telephone Network (PSTN). These two modes of operation are referred to as 'dispatch' and 'interconnect,' respectively. Centralized trunking systems are characterized by their co-location of all channels, their speed, channel loading capabilities and extensive feature sets as well as by their higher cost. Both types are presented in the discussions that follow.

Groups of users on a trunking system are known as 'Talkgroups' or as 'Fleets' and 'Subfleets.' A talkgroup or subfleet is the virtual equivalent of a private radio channel in a conventional system. Talkgroups can be configured in various hierarchies to permit group calls, group paging or to allow supervisors to hear all traffic on several unrelated workers' talkgroups. Talkgroups can be organized into virtual 'Systems' within the radio's programming, allowing related talkgroups to be grouped together for simplicity. Systems can also be programmed in the radio to allow the radio to access multiple physical systems, for example, a local system at a plant and a wide area system located on a mountaintop. Subscriber units have the capability to scan between talkgroups and systems, allowing tremendous flexibility to custom-configure the 'personality' of the trunked radio system as a whole. A trunking system is inherently private, with radios hearing only their intended talkgroups.

Frequencies assigned for 800 MHz and 900 MHz trunking systems in the USA have historically been exclusive assignments, free of competing co-channel users within a defined geographic area. As exclusive assignments, all assigned channels in the trunking system can be used on an equal basis. A trunking system with exclusive channel assignments is considered 'fully loaded' when 80 end users per channel are assigned to the system. For example, in a 5-channel system, the system would be considered fully loaded when 400 end users are loaded onto the system.

Depending on traffic patterns and the end-users' operating techniques, it may be possible to load more end users onto a system…..or a channel loaded to the point of gridlock may actually have fewer users. The use of interconnect on a system generally tends to lower the maximum possible number of users; the use of alternative data communication techniques, such as Kenwood's FleetSync, tends to allow more users on a channel. The negative impact of interconnect on loading numbers or the positive impact of FleetSync, can be dramatic. This impact must be carefully considered in for-profit trunking systems whose revenue stream is directly dependent on the number of end users loaded onto a system.

Although 800 MHz and 900 MHz trunking systems enjoy exclusive channel assignments, frequencies used for trunking systems at VHF and UHF are typically a mix of both exclusive and non-exclusive (shared) channels. Non-exclusive channels carry with them the requirement to not cause harmful interference to others already using the channel. Because of this, the FCC requires that these non-exclusive channels be monitored for other traffic before the trunking system assigns its users to the channel and they begin

their traffic. If competing traffic is using the channel, the trunking system must prevent interference by removing that channel from its available pool of trunking channels, thereby not assigning the channel for system traffic. In trunking systems, the end users themselves do not have the opportunity (or the requirement) to monitor a channel before beginning their transmissions. Therefore, it is required that the system itself monitors the non-exclusive channels for co-channel activity.

Two levels of monitoring requirements exist at VHF and UHF, their individual use required and specified jointly by the frequency coordinators and by the FCC. Level One monitoring is used when the trunking system is required to monitor a channel on the trunking system's receive frequency. This is easily done by monitoring the individual receivers in the trunking system for the presence of non-system traffic or unknown ID codes. This allows the trunking system itself to monitor the channel for traffic from mobiles in co-channel operations. When a co-channel mobile's activity is detected, the trunking system temporarily removes this channel from the pool of channels available for traffic assignment.

Although Level One monitoring allows the trunking system to easily monitor mobile activity from co-channel operations, it is possible that operations with more geographic separation may still cause interference to each other. This is because of the trunking system's inability to 'hear' mobiles that are outside its range, yet are well within range of their own repeaters.

In such cases, Level Two monitoring may be required. Level Two monitoring imposes the additional requirement to monitor the trunking system's transmit frequencies, listening for activity from the co-channel repeater's transmitter as a further indication of activity on the frequency. Level Two monitoring requires the use of a separate guard receiver tuned to the transmit frequency of the channel in question and gated to ignore the trunking system's own transmitter. Level Two guard receivers must be installed so that they can easily receive the protected co-channel operator's base station transmissions.

Since shared channels may be temporarily unavailable for the trunking system's traffic (depending on the presence or absence of traffic from the co-channel users), these channels reduce the number of end users that can be loaded onto VHF and UHF trunking systems. Unfortunately, there is no hard and fast number for this loading impact. The number of co-channel users on a specific channel, their traffic patterns and even their demeanor and tolerance of yet another co-channel user on what was once 'their' channel all affect the practical availability of these shared channels for trunking. Only practical experience can determine the impact of shared channels on potential loading numbers.

Often, agreements are made locally between what would otherwise be competing system operators, pooling their shared channels and converting each other's end users from conventional to trunked operations. In this case, both parties benefit by the more efficient use of available airtime on a much larger system. Sometimes a contentious relationship exists and neither operator can agree to work with the other. In such cases, interference complaints and their resolution are handled on a 'last in' basis, requiring the most recent licensee to protect the incumbent operations. Cases of malicious interference, sometimes caused by the conventional operator greatly extending his repeater's hang time to render the channel useless to the trunking system operator, are complex and often wind up in litigation. Clearly, cooperative agreements between co-channel operators create a win-win for all involved.

For more information on channel loading, monitoring and interference resolution, contact Kenwood U.S.A. Corp., Communications Division. For more information the on the statistical methods used for calculating telephone circuit loading (the basis for modern trunked radio systems), see www.erlang.com or do a web resources search for 'A. K. Erlang' (Danish mathematician and engineer, 1878-1929).

Modern Analog Trunked Radio Systems:

The following discussions present the basic concepts of the two different approaches to modern analog centralized trunked radio systems: Control channel-based trunking systems and distributed logic trunking systems. Both types are presented in comparison to provide a comprehensive understanding of their relative benefits and to allow rapid recognition of the two types. Digital trunking systems are outside the scope of this paper.

Control Channel-Based Trunking Systems:

In control channel-based systems, one channel is dedicated to high speed system control data, making only 4 channels of a 5-channel system (for example) actually available for voice traffic. Control channel-based systems use one central controller to manage the remaining traffic channels. Because all exchanges in a conversation between units occur on a single assigned traffic channel for the duration of the entire message, these systems are referred to as 'message-trunked' systems.

In message-trunked systems, all mobiles constantly monitor the control channel until they are assigned to an idle traffic channel. This assignment to a traffic channel is in response to a channel access request initiated by one of the subfleet's mobiles or by a wireline control command from a dispatch console. A mobile requests channel access by transmitting its request as a data exchange on the control channel's inbound frequency. Depending on the system's loading at that time and on the mobile's pre-determined importance in the system hierarchy, the mobile may be granted a channel immediately or may be placed into a queue for channels as they become available.

Once a traffic channel assignment is granted and mobiles who are members of the requesting unit's subfleet are grouped together on the selected free channel, the requesting mobile is notified by a beep from the system. Upon hearing the 'proceed' beep, the end user re-keys his transmitter and the conversation begins. Depending on the system's loading and the user's placement in the system's queue, the time required for assignment to a traffic channel can vary greatly from a fraction of a second to tens of seconds.

Once assigned to a traffic channel, the subfleet's mobiles remain on this assigned channel during all exchanges in the entire conversation and through the idle 'hang time' of the repeater, the time during which the repeater remains transmitting as it waits for another exchange of conversation. Hang time is dead air time required in the control channel-based architecture, but is unusable for other system traffic as the system anticipates follow-on traffic within the active subfleet. Depending on traffic patterns, the hang timer can greatly impact the system's total available air time if set improperly.

The traffic channel operates much the same as a conventional carrier-squelch repeater until the repeater's hang timer is exceeded. When the hang timer expires because of the mobiles' inactivity, the system assumes the mobiles have finished their traffic and it finally unkeys the traffic channel's transmitter. As the mobiles detect the loss of the repeater's signal on the assigned traffic channel, they automatically begin scanning the pool of channels in the trunking system to identify and revert back to the control channel to await further instructions. If an end user in the active subfleet delays its response (answering a question, for example) and exceeds the hang timer, another request for service must be made to the trunking system, another traffic channel assignment must be made and the cycle is repeated.

Because of the hang time requirement and the overhead requirement for continuous data on one channel, control channel-based systems are only moderately efficient forms of trunking. However, the continuous exchange of high speed data between the trunking system and the subscriber units allows control channel-based systems to incorporate data-related features such as hierarchy queueing, over-the-air reprogramming, MDT data messaging and emergency channel pre-emption. Additionally, since the system's intelligence is resident in the central controller, dispatch consoles may be directly interfaced with control channel-based trunking systems. Since all voice traffic occurs on carrier-squelch conventional repeater channels, signal-to-noise voting is easily implemented on these systems.

Most of the system intelligence in control channel-based systems resides in a central controller located at the repeater site. This central controller is quite complex and has a risk of single-point total system failure. Subscriber units in control channel-based systems are generally simple radios, their operation substantially dependent on continuous instructions from the central controller via the control channel. If a mobile roams outside the trunking system's coverage footprint (and loses control channel information), the mobile can be programmed to display an out-of-range indication or to revert to pre-programmed conventional talkaround channels.

Most versions of modern control channel-based systems also allow automatic reversion of the system's repeaters to a failsafe mode in the event of the failure of the central site controller. In this case, mobiles losing the data stream from the control channel are pre-programmed to revert to specific system channels in their conventional mode to provide basic communications in the event of failure of the trunking system's controller.

Some versions of control channel-based systems temporarily interrupt the control channel data stream to allow that channel to be used as a traffic channel when all other channels are in use. This allows a 5-channel trunking system to actually operate 5 voice traffic channels on a temporary basis. However, during the control channel's temporary operation as a voice channel, all interactive data services to all mobiles are suspended. If a long conversation takes place on the former data channel, this has the effect of 'orphaning' the remainder of the entire system since no traffic assignments can be made until the data channel is restored.

Because of the continuous, 24 hr a day transmitter requirement for the data channel, control channel-based trunking systems rotate the data channel assignment each day to equalize wear on the RF equipment. The subscriber units in these systems automatically scan the available channels to identify that day's data channel, then stop on the data channel and await assignment instructions.

Both of the two major control channel protocols used in the USA are closed architecture and are proprietary to their respective manufacturers. The closed architecture and absence of marketplace competition causes these systems to generally be very expensive. A third protocol, open-architecture and non-proprietary, is widely used overseas. All three major control channel trunking protocols are incompatible and mutually exclusive.

Distributed Logic Trunking Systems:

The other approach to analog trunking, known to Kenwood as Distributed Logic Trunking, uses sub-audible data transmitted on <u>all</u> channels for its system control, thereby making all channels available for coexistent, simultaneous voice traffic. Each portion of a conversation exchange occupies a traffic channel for only the duration of the exchange itself; end users may seamlessly receive multiple traffic channel assignments during the course of a complete conversation. This architecture is referred to as a 'transmission-trunked' system.

In transmission-trunked systems, each channel operates for only the length of a single transmission (no wasted hang time) in the dispatch mode. However, since an interconnect mobile must remain on the same channel as its physical PSTN telephone line, interconnect traffic operates in a message-trunked mode. Variations of interconnect service allow such functions as autodial upon PTT, call restriction (different levels of users have different interconnect calling privileges), one-way and two-way paging, and manual and automatic dispatch networking.

The distributed logic trunking format accommodates a total of 20 channels per system and provides simultaneous voice traffic on <u>all</u> channels by allowing its sub-audible control data to co-exist with voice traffic. Kenwood distributed logic trunking products are compatible with all open-architecture LTR® format products (LTR® is a registered trademark of E. F. Johnson Company).

In a distributed logic format, one trunking logic controller is required per RF channel. In this system architecture, the intelligence is 'distributed' between all channels, minimizing the risk of a single-point failure crippling the entire system. The trunking controllers perform all trunking logic processing to and from the mobiles and between other controllers within the same system. Subscriber units in distributed logic trunking systems are feature-rich, since the system's intelligence is shared between the subscriber units and the trunking system itself.

Since the system's intelligence is shared between its subscriber units and the trunking system, dispatch consoles are interfaced over the air using control stations. Because of the requirement to transport and replicate the sub-audible data over phone lines or RF links (circuits with 300 Hz–3 kHz audio bandwidth limitations), distributed logic trunking systems are not generally candidates for signal-to-noise voting. A new voting product manufactured by JPS Communications uses DSP techniques to shift the sub-audible data up into the audio circuit's passband for transport, then shift it back to sub-audible and recover and replicate it at the trunking system as the voted output.

A system operator may have one or more systems to provide coverage over a wide geographical area. These systems can be used individually or can be networked together to enable users on different systems to talk with each other. This networking requires the installation of one or more network switches, similar in concept to an automatic telephone PBX. A recent enhancement of the distributed logic protocol is Trident MicroSystem's PassPort protocol. PassPort, a complex and feature-rich networking architecture, is outside the scope of this paper.

Distributed Logic Trunking Technical Details:

In distributed logic trunking systems, mobiles are 'homed' to a specific RF channel. This home channel is their default channel and will be used if it is not busy with other traffic. If the mobile's home channel is busy, the trunking system will trunk the mobiles to a free channel within the system, continually reassigning the mobiles as necessary following each segment of the conversation exchange. It is important to note that any channels assigned as home channels <u>must</u> be exclusive-use channels. Trunk-to channels (the non-home channels in the trunking pool) may be either exclusive or shared channels.

Controllers within a system are linked together via a high speed repeater data bus. This bus allows all system repeaters to know the current status of all other system repeaters (free or busy) and also identifies which mobile talkgroup is currently using which repeater.

This data bus is a synchronized serial bus divided into 20 repeater time slots, one ID validation time slot and one spare (unused) time slot. Each repeater in the system (20 maximum) continually updates the bus by placing the Home Channel ID of the mobile currently using the repeater in its own time slot on the bus. Each controller also reads the data in all the other 19 repeater time slots to find out if one of its mobiles (a mobile homed to this repeater) is using another repeater (has been trunked to another available channel).

If it finds one of its own mobiles, this data is transmitted out as collection data so that other mobiles listening with the same home channel and ID will be sent to the non-home (trunk-to) repeater to receive their call. Additionally, free repeater information is continually shared to all controllers so that all transmitted data contains free repeater information. This updates idle mobiles so that they always know which repeater is available to make a call.

Interaction between trunked mobiles and a distributed logic trunked repeater system is accomplished through the use of continuous sub-audible data messages or data packets. Being sub-audible, they are transparent to the radio user and co-exist with voice traffic. Microprocessors in the mobiles interpret these data messages and use them to control channel switching, transmission and audio muting.

Each distributed logic data packet is divided into synchronization bits, the area bit, go-to instructions, home channel information, ID code information, free channel information and a calculated cyclic redundancy check number. Inbound data packets and outbound data packets are the same length: 40 bits, each bit 3.3 mSec in length for a total of 132 mSec per data packet (or approximately 300 bps). In the following example, all bits (with the exception of the fixed sync bits) are illustrated as 1s:

SYNC	AREA	GO-TO	HOME	ID CODE	FREE CHAN	CRC
101011000	1	11111	11111	11111111	11111	1111111
(fixed sync msg)	1 or 0	5 bits	5 bits	8 bits	5 bits	7 bits

(Word length = 40 bits total.)

The sub-audible data format is a unique, non-repetitive waveform as illustrated below. Transmitted data deviation on wideband channels is $\pm$ 1.0 kHz; data deviation on narrowband channels is $\pm$ 800 Hz:
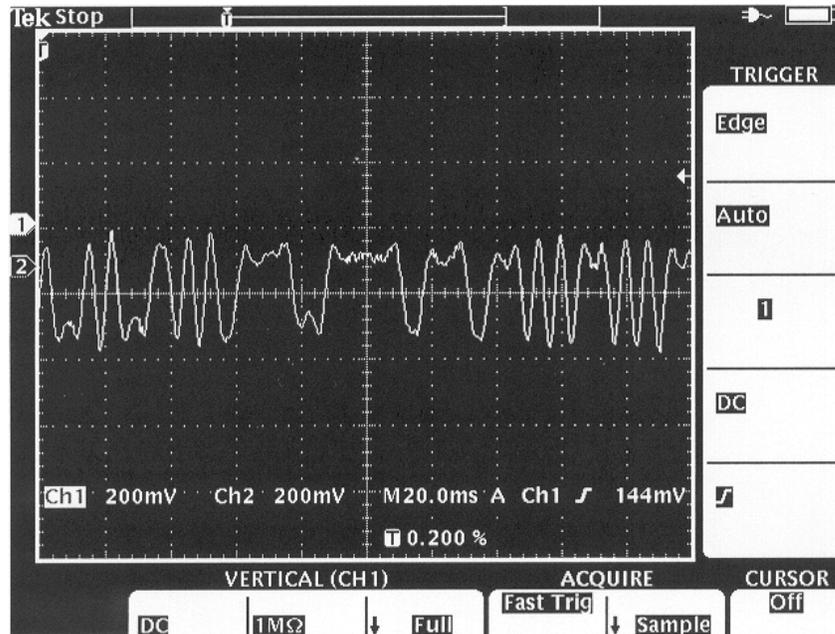
Notice the small peaks on the leading and trailing edges of the series of 1s at the center of the graticule in the example above. It is crucial in balancing a transmitter's modulator that these peaks, sometimes referred to as 'Batman's Ears,' are as close to the same level as possible (are directly across from each other horizontally). This ensures the transmitter is optimized to accurately transmit the ultra-low frequency components of the distributed logic waveform, thereby accommodating any areas of sustained 1s and 0s that may appear in the data.

There are five data packet types.

    Mobile-to-Repeater:

        REQ (Request for Service): requests and maintains access on a system channel.
        EOT (End of Transmission-Mobile): signifies the end of a mobile's transmission.

    Repeater-to-Mobile:

        COL (Collection): responds to a REQ and collects all called mobiles to
            the repeater.
        EOT (End of Transmission-Repeater): signifies the end of transmission to
            the mobile.
        IDLE: sent once every ten seconds when a repeater is inactive (optional).

The mobile listens on its home channel to data messages for inbound calls and for free repeater information. This occurs at initial power up, in standby mode and after every PTT release. Also, during scanning of multiple systems, the mobile will scan from one system's home channel to the next system's home channel 'listening' for calls.

Each system can be further identified by an 'Area Bit,' either a 1 or a 0 set into the data stream. This area bit can be used to minimize interference from neighboring systems (area bits alternated between systems with overlapping coverage) or to improve system security by complicating unauthorized airtime access.

By convention, distributed logic trunking system channels are often referred to by their bus time slot assignments as repeater channel numbers 01 through 20. However, each RF channel frequency pair at 800 and 900 MHz uses a three-digit 'FCC Channel Number' to designate the assigned RF frequencies (a lookup table defined by the FCC). This FCC Channel Number (1 to 911 at 800 MHz, 1 to 399 at 900 MHz) should not be confused with the repeater channel numbers (01 to 20) that designate the repeater number within the distributed logic system.

To eliminate confusion, Kenwood refers to repeater numbers with two digits (below channel 10), appending the system's sync master with the letter 'M' (example: 01M, 02, 03, etc.). At 800 and 900 MHz, channel numbers are referred to by three digits (example: 001, 452, 489, etc.). Although some timing advantages still remain, early systems required balancing the repeater numbers (time slots used) across the 20 available. For example, instead of clustering a 5 channel system together as 01M, 02, 03, 04, 05, time slot balancing uses 01M, 05, 09, 13, 17 to equalize the gaps between bus data. Kenwood continues the legacy time slot balancing as its default system setup.

Early distributed logic mobiles used a periodic idle channel packet sent by all repeaters in the trunking system every 10 seconds (during a channel's idle periods) to all the mobiles to confirm the system's presence. Modern radios no longer need this idle channel packet as a periodic update during idle periods and, especially in the case of shared VHF and UHF frequencies, it is often disabled as a courtesy to co-channel users. On systems where the idle channel packets are active, idle channel packet activity can be an important diagnostic tool by using a radio programmed as conventional, carrier-squelch on a site's individual channels.

The FCC requires periodic identification of transmitters, either by vocally announced call signs or by automatically transmitting the call sign in Morse code. All modern distributed logic controllers are capable of Morse code identification (CWID) of the channel and accommodate normal CWID hold-off to prevent end users from hearing the CWID. Identification requirements vary; at 800 and 900 MHz only the first channel in the system is normally identified; at VHF and UHF, all channels must be identified individually.

ID Codes / Validation:

Distributed logic trunking systems have a system architecture maximum of 20 channels per physical system. Each channel in a system has a maximum of 250 talkgroup ID codes available. This means that a 20-channel system can have a maximum of 5000 ID codes. Groups of related users (talkgroups) are assigned one of these available ID codes. Any number of users can share the same ID code and communicate with each other.

The complete talkgroup ID is specified as being the home channel plus the individual ID within that channel, such as 05-221: Home channel 05, ID code 221. These IDs are often divided into usage blocks in each controller so blocks of IDs can be designated as dispatch, other blocks as interconnect, others as paging, etc.

Often, the system operator finds it advantageous to pre-assign certain ID codes as system maintenance codes (test codes) or a product demonstration codes. This allows maintenance or demonstration activities to take place without impacting customer traffic.

By convention, Kenwood uses ID code 100 as dispatch test, ID code 200 as interconnect test and ID code 201 as interconnect test (second language voice prompts).

The trunking system is capable of determining whether a requesting mobile is authorized to use the system. This process is called 'validation' and is intended to prevent theft of service. Mobiles are identified in the system by their area bit, home channel and ID code. If the validating controller (the controller designated as the sync master) confirms in its database that the ID is authorized to use the repeater (the ID is valid), the talkgroup's members are assembled and communication takes place normally.

If the validating controller detects an invalid ID, the logic unit places the invalid Home# and ID# into time slot 21 of the data bus. This information is shared with all other logic controllers in the system. If the invalid mobile attempts to access any repeater, the repeater will transmit end-of-transmission data packets which cause the other mobiles in this invalid talkgroup to squelch their audio and return to the standby mode. Although the controller handshakes normally with the invalid mobile requesting service, its repeat audio is inhibited and is not transmitted. These two measures prevent unauthorized communication, despite the best efforts of experienced system hackers. Validation can be toggled on or off in the controller on a per-ID basis, allowing the system operator to control which subscriber talkgroups are authorized to use the system. This is especially useful in controlling non-paying customers' unauthorized use of commercial for-profit systems.

An advanced-technology system which assigns unique individual ID numbers to each subscriber unit can provide security against airtime piracy on an individual user basis. This protects the for-profit commercial system owner against unauthorized access by unscrupulous users who claim to have only a few units, but who have instead cloned a large number of units. This system uses unique, imbedded 10-digit Electronic Serial Numbers and is referred to as ESN Validation. In recent years, however, ESN Validation and the controllers that used it have been replaced by PassPort systems which also use their own version of individual unit ESN Validation.

Typical Dispatch Operation:

In general, a dispatch ID code is assigned to an individual talkgroup. These individual talkgroups may also be thought of as 'private channels' in a virtual sense. If the mobile is to communicate with several talkgroups, then it will be programmed with appropriate ID codes for each talkgroup.

For dispatch calls, the user selects the desired ID (a front-panel mnemonic such as 'SECURITY') and presses and holds PTT to request system access. The mobile immediately transmits a data packet on the system's pre-designated free channel that is received and decoded by that channel's controller, which in turn communicates with the other controllers in the system via the high speed data bus. The system encodes the ID code and go-to instructions into its outbound data packets, assembling ('collecting') the other units of the talkgroup onto the active channel. As this happens, the mobile acknowledges to the requesting end user that the system has granted him access and the end user begins transmitting his voice traffic. This process is referred to as 'handshaking' and is completed in approximately 280 mSec.

A handshake confirmation tone that indicates system access has been granted (known as a 'proceed' or 'go-ahead' beep) is often used with distributed logic systems. When the end user first keys his microphone, the proceed beep is heard in the mobile's speaker audio 280 mSec later and the end user begins his transmission. Only one PTT action is

required (rather than the two required in control channel-based systems); end user instructions when the proceed beep is enabled are simple: 'Talk after the beep.'

This handshaking process is duplicated when the called mobile unit responds to the caller. In transmission-trunked systems, portions of a dispatch conversation exchange may occur on a different repeater in the system, the system constantly reassigning repeaters as needed, and doing so transparently to end users.

If all channels in the system are busy with traffic, a 'busy' indication is displayed on the mobile and its PTT is inhibited. If the mobile rekeys his transmitter a few seconds later, it is highly probable that a free channel will be available for assignment since there is no hang timer overhead and all channels are equally available for traffic. Because of the very high statistical probability of channel access, transmission-trunked systems enjoy a very low probability of call blocking. Transmission-trunked systems are considered the most efficient form of analog trunking.

If a mobile's initial attempt to handshake with the system is unsuccessful (for example, because the mobile has ventured beyond the system's coverage footprint), the radio will re-send the handshake REQ data packet up to 4 more times (5 attempts total) in rapid sequence while the PTT is held. If handshaking is still unsuccessful after 5 attempts, a no-service tone (a denial tone) will be heard in the mobile's speaker.

Typical Interconnect Operation:

An interconnect ID (also known as RIC: Radio InterConnect) is assigned to those mobiles that need access to the local PSTN. This gives the mobile the ability to make and receive telephone calls. It is important to note that while all channels in a trunking system are capable of dispatch operation, only those channels with special interconnect controllers are also capable of interconnect operation.

For mobile-to-landline interconnect calls, the user selects an interconnect talkgroup ID (a front-panel mnemonic such as 'PHONE') and presses PTT. Kenwood trunked products will attempt to access only those channels in a system that have been designated as interconnect in the radio's programming. Once access is made, the repeater's controller validates this ID code as an interconnect ID and connects the repeater's audio to the telephone line. The requesting mobile hears the familiar Telco dial tone and dials the desired number using his DTMF microphone or keypad.

When the call is complete, the mobile presses '#' to terminate the call or allows the call to simply time out (the action of a mobile inactivity timer). If a call's length approaches the allowable time limit for the privileges assigned to this ID code, a beep notifies the mobile his time is about to expire, then a few seconds later a voice prompt notifies him that the call timer has been exceeded and the interconnect call has been terminated.

For landline-to-mobile calls, the interconnect controller is called like a normal telephone. When the controller answers, it voice-prompts the caller to overdial the mobile's ID code (for example, 05221 for talkgroup 05-221). The mobile hears a telephone-like 'ring' from the radio's speaker to indicate the incoming call, presses PTT to respond, and the call proceeds normally. Full duplex mobiles (a rarity today) allow conversations to proceed just like a landline call; half-duplex mobiles require a PTT from the mobile when the trunking system end user wishes to talk to the landline caller.

Several fixed and variable timers are available to manage the airtime used on a per-ID basis. Variable timers can be used to monitor overall system loading and dynamically adjust the maximum time allowed for interconnect calls during periods of high dispatch

traffic. Alternating timers can be used to allow longer call time (fixed length increments) during evenings or weekends.

In addition, call records may be downloaded from the system controllers to be used in manual accounting or billing of airtime per ID code. This important feature allows a system operator to identify those users who may be abusing their interconnect privileges, or allows departmental or end-user billing for their share of system operating costs. In for-profit commercial systems, this feature is normally coupled with a comprehensive billing software package to provide the system owner's billing and revenue stream from the trunking system.

Kenwood KSG-11050 interconnect controllers prompt the end users using tones while KSG-11100, KSG-11120 and KSG-12049 interconnect controllers prompt end users with digitally stored voice audio. The KSG-11120 also provides pre-recorded bi-lingual voice prompts, assignable on a per-ID basis. By using the KSG-12049 controller, the system operator can record his own custom voice prompts, changeable at any time.

Using KSG-11120 or KSG-12049 controllers, it is also possible to use 4-wire DID (Direct Inward Dialing) lines which directly signal the controller for the proper mobile ID. This provides direct dialing and does not require the caller to overdial the ID code (each Interconnect ID has its unique phone number). Additionally, KSG-11050, KSG-11100, KSG-11120 and KSG-11049 interconnect controllers may be configured to use 4-wire E&M control circuits.

Programming Subscriber Units:

Mobiles and portables typically have programming arranged to accommodate multiple systems, each system with multiple talkgroup IDs. Since a mobile can have more than one ID per system, a function known as Group Scan can be enabled in the mobile so that all the selectable IDs are scanned when listening to the system's home channel. The mobile can now receive a call from any of the programmed groups. Group Scan is enabled in the mobile on a per-system basis and operates independently of System Scan (i.e., the mobile can Group Scan independently of whether or not it is System Scanning).

Trunked mobiles normally Group Scan only if the microphone is on-hook (unless programmed to enable off-hook Group Scan). If the mic is off-hook, then only the selected group is decoded. However, if the Interval Scan feature is enabled, Group Scan occurs regardless of the mic hookswitch status. Kenwood portables Group Scan all the time (if enabled), since there is no hookswitch on a portable. These portables have a Group Lockout feature that allows individual groups to be deleted from the Group Scan list, if desired.

Mobiles and portables can be programmed with multiple systems. Systems may have as many as 20 channels each and are often located to provide coverage of specific geographic areas. For wide area coverage, many systems may be built to cover adjacent areas, often having overlapping coverage. The mobile can be programmed for any or all of these systems so that communication is available over a wide area. Systems may also be programmed as convenience groupings of related talkgroups on the same physical trunking system.

System Scan allows a mobile to scan these individual systems, since a call could come through any of the programmed systems. When System Scanning, the mobile will scan from home channel to home channel, listening for calls. If Group Scan is also enabled, the mobile will scan for all group IDs as it checks the home channel of each system scanned.

As a mobile scans from home channel to home channel during System Scan, it will stop if it detects carrier for a short time period of three data packets in length (for example). This is done to make reasonably sure that it will detect a call during this time window (finding a matching data packet, if one exists). However, this is not always foolproof. For example, a busy system of 20 channels could have as many as 20 data packets coming from a home channel data packet stream (1 packet is the mobile currently using the home channel, plus 19 additional packets coming off the system data bus because of other trunked mobiles). If, for example, the calling packet is 11th in the data packet stream and the mobile stops for only three data packets, it could miss the call until its scanning sequence returns it to this channel for an additional scan period.

Scan Weight is a programmable feature in the mobile that allows the mobile to listen longer for a call. By increasing the Scan Weight, the probability of missing a call is greatly minimized. Although Group Scan occurs very quickly, System Scan is significantly slower because of the dwell time required to examine the serial contents of the home channels' data packet streams.

Mobile Data Applications:

Mobile data applications can significantly reduce a system's airtime requirements (or, conversely, increase the maximum loading possible) by offloading lengthy voice traffic exchanges onto the data system. What might otherwise be a 20 second exchange of voice traffic between two units can instead require only a few milliseconds as a mobile data exchange. Examples of mobile data systems are MDT systems, remote meter reading systems, GPS systems, FleetSync, etc. Typical wideband data speeds are 2400 bps; typical narrowband data speeds are 1200 bps. Mobile data traffic is inband audio and is handled transparently by the trunking system's repeaters.

Mobile data traffic can co-exist with voice traffic on an equal, non-interfering basis in distributed logic trunking systems. In such applications, the mobile data traffic is simply assigned an ID code in the trunking system. Channel handshakes, access and data exchanges occur just as with voice traffic.

Unfortunately, mobile data traffic operating as an ID code on a distributed logic trunking system still requires a 280 mSec system access time, just as with voice traffic. If only small numbers of data messages take place during a day, this timing overhead is not usually a problem. However, if large numbers of data messages are to be exchanged, the channel access time can quickly become significant, especially considering that the actual data traffic may itself be only a few milliseconds in length or only a fraction of the channel access time overhead requirement.

Although there are no ironclad rules, in some cases it may be more efficient to take one of the trunking system's channels and convert it to conventional channel exclusively for mobile data. In this case, conventional channel access by data units would typically require only 10-20 mSec, greatly improving the data throughput speeds and, by offloading the data traffic from the trunking channels, further increases the loading capabilities of the trunking system's remaining voice channels.

End-User Migration from Conventional to Trunking:

A new trunking system can sometimes be installed and commissioned from scratch using previously unused frequencies. In this case, all end-users can begin using new trunked subscriber units at the same time. However, when several conventional channels currently operating as community repeaters are re-licensed and combined into a new trunking system, it is sometimes necessary (especially in for-profit systems) to accommodate both legacy conventional users as well as new trunked users on the resulting group of frequencies.

Because of the increased efficiencies of trunking, the system operator benefits greatly by converting all end-users to the trunking format as rapidly as possible, thereby maximizing his available airtime. In reality, there may be some users reluctant to purchase new trunked radios who may want to continue as conventional users indefinitely. This situation often occurs when groups of end-users (individual companies, for example) own their subscriber units and do not immediately upgrade to new trunked units.

This creates the dilemma of the frequency as a valuable resource in the new trunking system vs. the value of the customer's continued business. To solve this dilemma and provide a migration path for the end users, modern distributed logic trunking controllers allow conventional CTCSS or DCS coding to be programmed as an overlay block in the ID code assignment matrix. This allows the existing conventional users' traffic to be recognized and processed by the trunking controller as if it were a conventional controller. With the possible exception of reverse-burst squelch tail elimination (there are several standards in use in the industry), most end-users are unaware of any differences. Programming methodologies vary; refer to individual controller operation and programming manuals for details.

It is important that any conventional users are assigned *only* to trunk-to channels, not to channels used as home channels in the trunking system. Stated conversely, any channels in the new trunking system that will continue to have conventional users cannot be used as home channels in the new trunking system.....until the legacy conventional users on these channels have migrated to trunking. It is also important that no new conventional users are assigned to the new trunking system; all new users must be trunking users.

If trunking users were homed to a channel that also had conventional users programmed to it, a serious conflict would exist during the period in which the conventional user is using the channel. When the conventional traffic is using the channel, the channel contains the conventional user's CTCSS or DCS coding and lacks the LTR sub-audible data stream. Since the home channel is a trunking radio's default channel (the channel it monitors for assignment instructions), this has the effect of orphaning all trunking users homed to that channel until the conventional traffic has ended. Clearly, this situation must be avoided.

But by programming the conventional users only onto trunk-to channels (conversely, by not using channels with legacy conventional users as home channels), this allows the conventional users' traffic to co-exist in the trunking pool on a shared basis. For example, if a trunking user has been assigned (trunked) to one of these shared channels, the conventional user (by monitoring the channel before transmitting) must wait for channel access just as if the channel were in use by another conventional user. When the conventional user is using the shared channel, the trunking system recognizes the presence of his traffic just as if it were an external co-channel user, it activates the RDD circuit and temporarily removes the shared channel from the trunking pool. This conventional / trunking sharing on trunk-to channels allows the new trunking system to serve the needs of both the legacy conventional user as well as the new trunking user.

RF Considerations:

Although detailed discussions involving transmitters, receivers, combiners and antennas are beyond the scope of this paper, a few general guidelines can be offered:

It is important to understand that because the trunking system seamlessly assigns identical channels, all channels in a trunking system must have exactly the same characteristics…..audio as well as RF. It is absolutely critical that the data and the repeat audio amplitudes on each of the repeaters are set to be exactly identical and no differences can be detected by the end users.

It is also very important that all channels in the trunking system have similar antenna apertures and radiated powers from the antenna system. This requires not only that the combining efficiency is matched from channel to channel (the same power on each channel is fed to the transmit antenna), it also requires identical transmit and receive antenna patterns.

Great care must be taken to ensure adequate isolation and freedom from desense. Desense caused by improper cable routing or caused by transmit and receive antennas mounted too close to each other can be a big problem, especially on multi-channel VHF and UHF systems. Although at 800 and 900 MHz the transmit and receive frequencies are paired and widely separated (by 45 MHz and 39 MHz, respectively), paired transmit and receive frequencies at UHF are separated by only 5 MHz (only 3 MHz in 490-512 MHz). And since there is no prescribed channel pairing at VHF, these transmit and receive frequencies can be very problematic. Only premium transmitter combiners, receiver multicouplers and preselectors should be used on multichannel systems.

One of the most important system design considerations in multichannel systems at UHF and VHF is the width of the guard band between the closest transmit and receive frequencies. For example, if a proposed system consisted of transmit frequencies at 454, 454.5 and 461 MHz, the system's receive frequencies would be at 459, 459.5 and 466 MHz. Notice the very small guard band between the 454.5 MHz channel's receive frequency at 459.5 MHz and the 461 MHz transmit channel. It would be virtually impossible to adequately filter the 461 MHz transmit channel to prevent severe desense from crippling the 459.5 MHz receiver and perhaps the entire receiver subsystem. As a general rule, 2.5 MHz of guard band is considered the minimum for proper system operation.

Another important consideration is the presence of intermodulation products caused by combining multiple channels together in a combiner. Although the dual isolators used in modern transmitter combiners are excellent in helping control intermodulation, a mathematical analysis should always be performed during the system planning stages to evaluate the intermodulation risk.

Although individual channel duplexers may be required at VHF, duplexing the output of a multichannel transmitter combiner with the input of a receiver multicoupler should be avoided. Instead, separate transmit and receive antennas should be used, mounted so their physical separation provides adequate RF isolation. If mounted vertically on a tower, 10' center-to-center vertically is adequate at 800 and 900 MHz, 40' center-to-center is generally adequate at UHF. VHF antennas may require careful planning to group individual transmit antennas together and locate a receive antenna 50' (or more) above the transmit antennas. Refer to published antenna separation / isolation nomographs for horizontal mounting or for diagonal offset mounting. In all cases, carefully check the actual desense when the system is installed by using an adjustable line sampler, testing for desense with all possible combinations of receive frequencies and transmitters keyed.

For Additional Information:

For more information on subscriber unit programming and features, refer to the service and programming manuals for specific radio models. Additional publications and training on subscriber units are available from Kenwood U.S.A. Corp., Communications Division.

For assistance with system licensing, engineering, design, site acquisition or turnkey project management, installation and maintenance, call Kenwood U.S.A. Corp., Communications Division at 1-800-TRUNKING (or 678-474-4700).

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