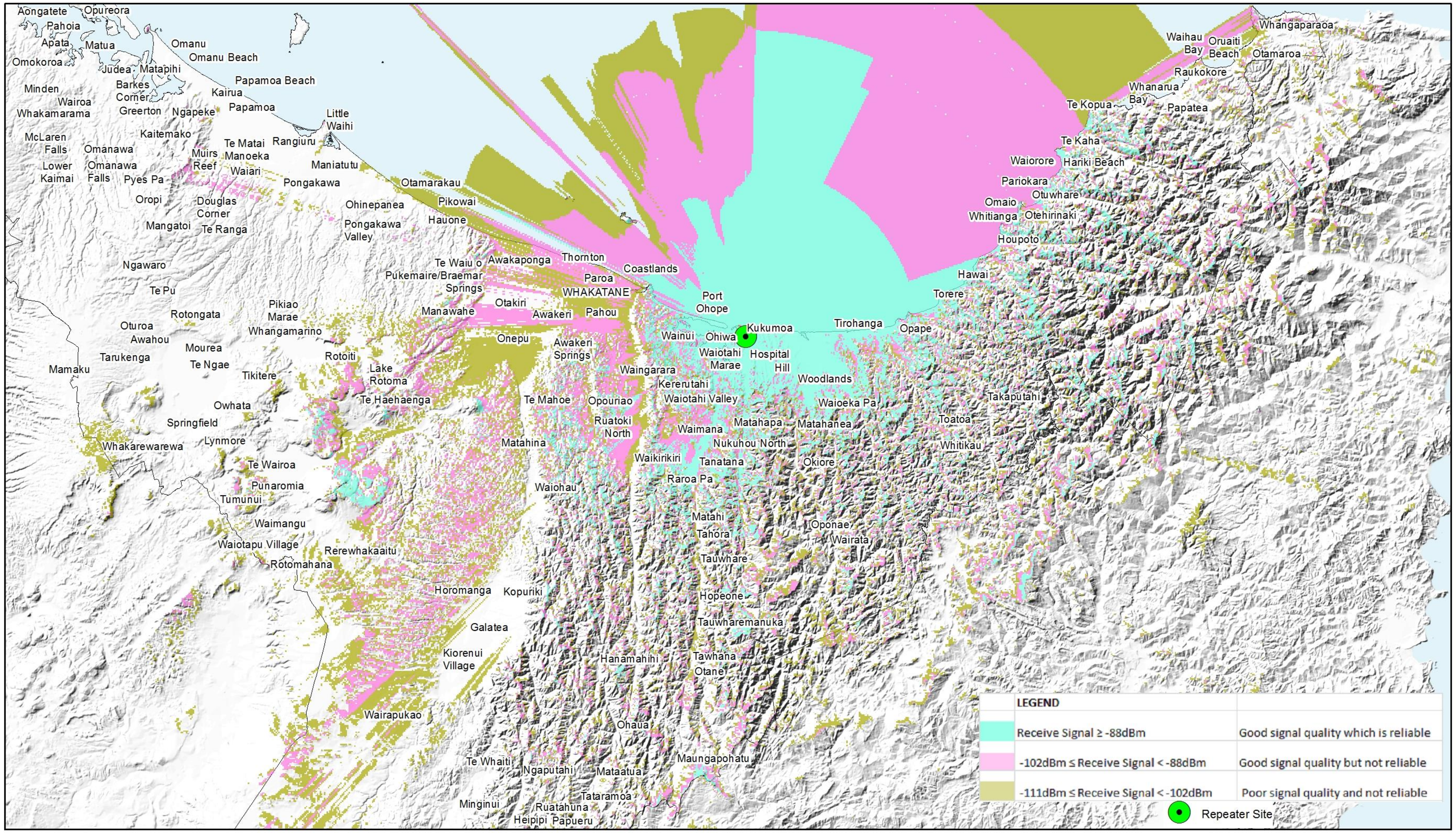
8. Ohiwa Peninsula Hill



HORIZONTAL DATUM: New Zealand Geodetic Datum 2000
For practical purposes, NZGD2000 equates to WGS84
VERTICAL DATUM: Moturiki
PROJECTION: New Zealand Transverse Mercator 2000

Radio Telephony Coverage - Ohiwa Peninsula Hill

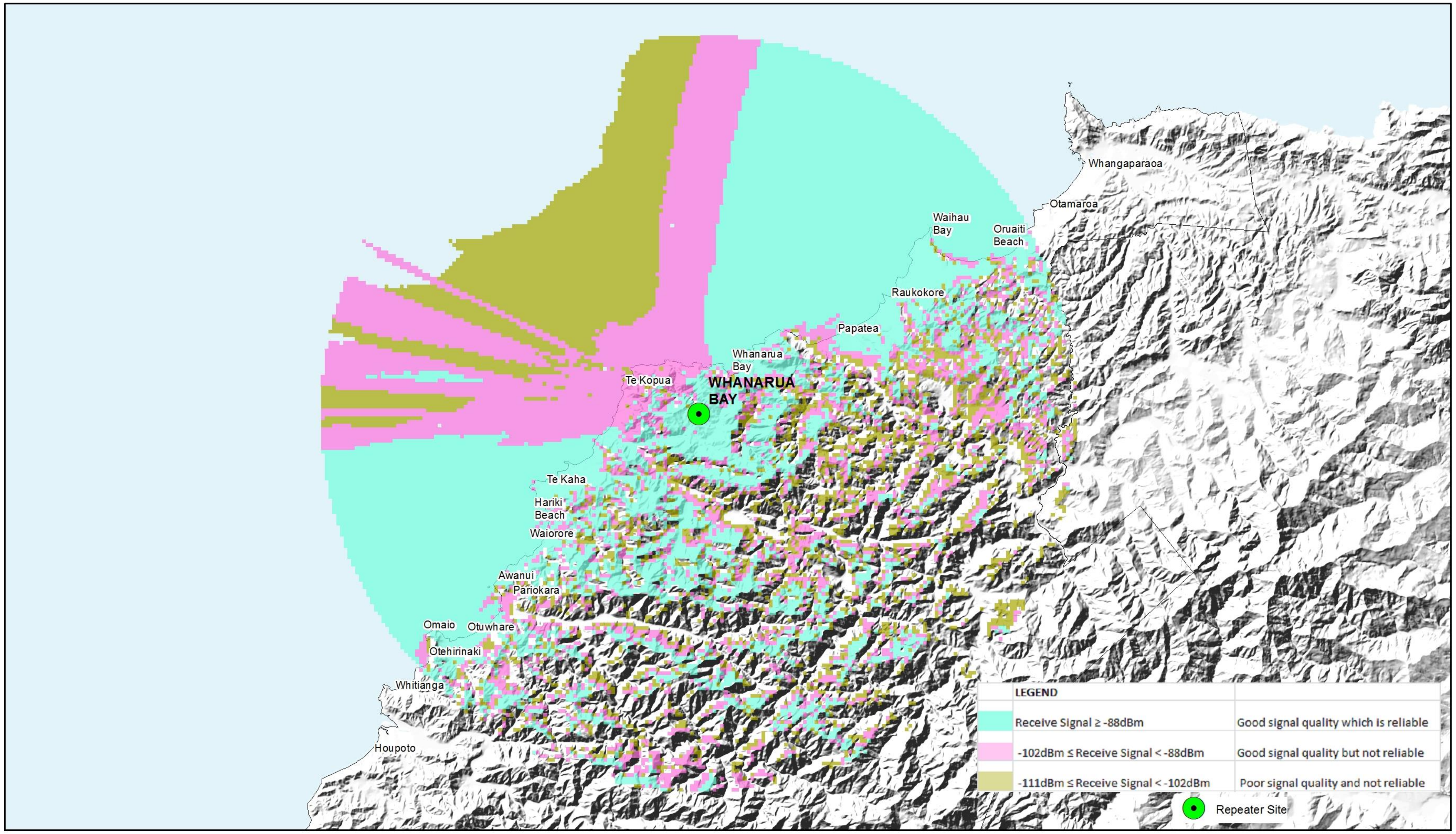
Scale 1:750000 (A4)

10 0 10 20

Kilometres

GIS-490081
Sheet 3 of 10
Printed 20/02/2015

9. Whanarua Bay



HORIZONTAL DATUM: New Zealand Geodetic Datum 2000
For practical purposes, NZGD2000 equates to WGS84
VERTICAL DATUM: Moturiki
PROJECTION: New Zealand Transverse Mercator 2000

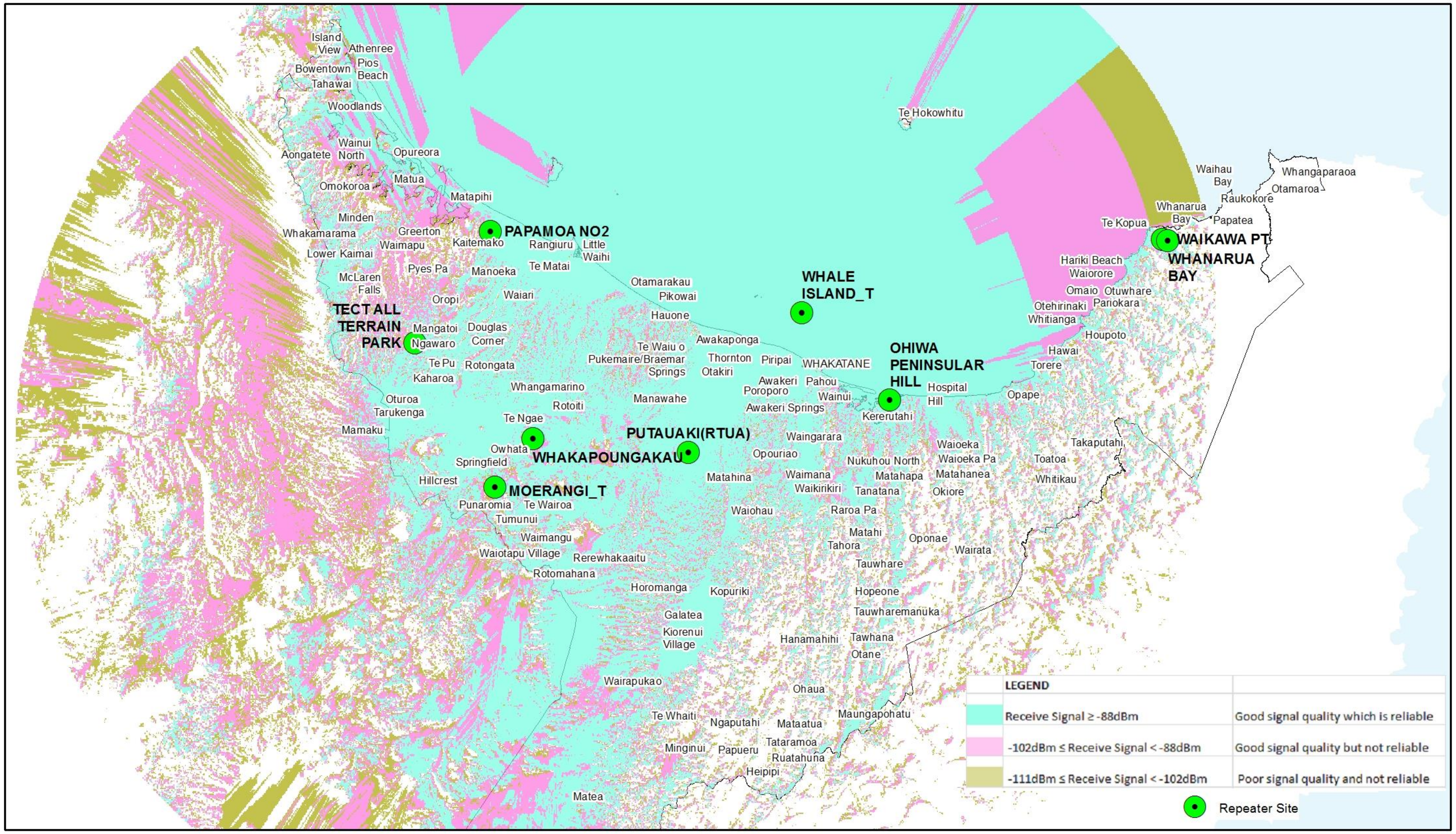
Radio Telephony Coverage - Whanarua Bay

Scale 1:275000 (A4)

5.5 0 5.5 11
Kilometres

GIS-490081
Sheet 8 of 10
Printed 20/02/2015

10. BOPRC BAU Voice Coverage



Bay of Plenty REGIONAL COUNCIL

HORIZONTAL DATUM: New Zealand Geodetic Datum 2000
For practical purposes, NZGD2000 equates to WGS84
VERTICAL DATUM: Moturiki
PROJECTION: New Zealand Transverse Mercator 2000

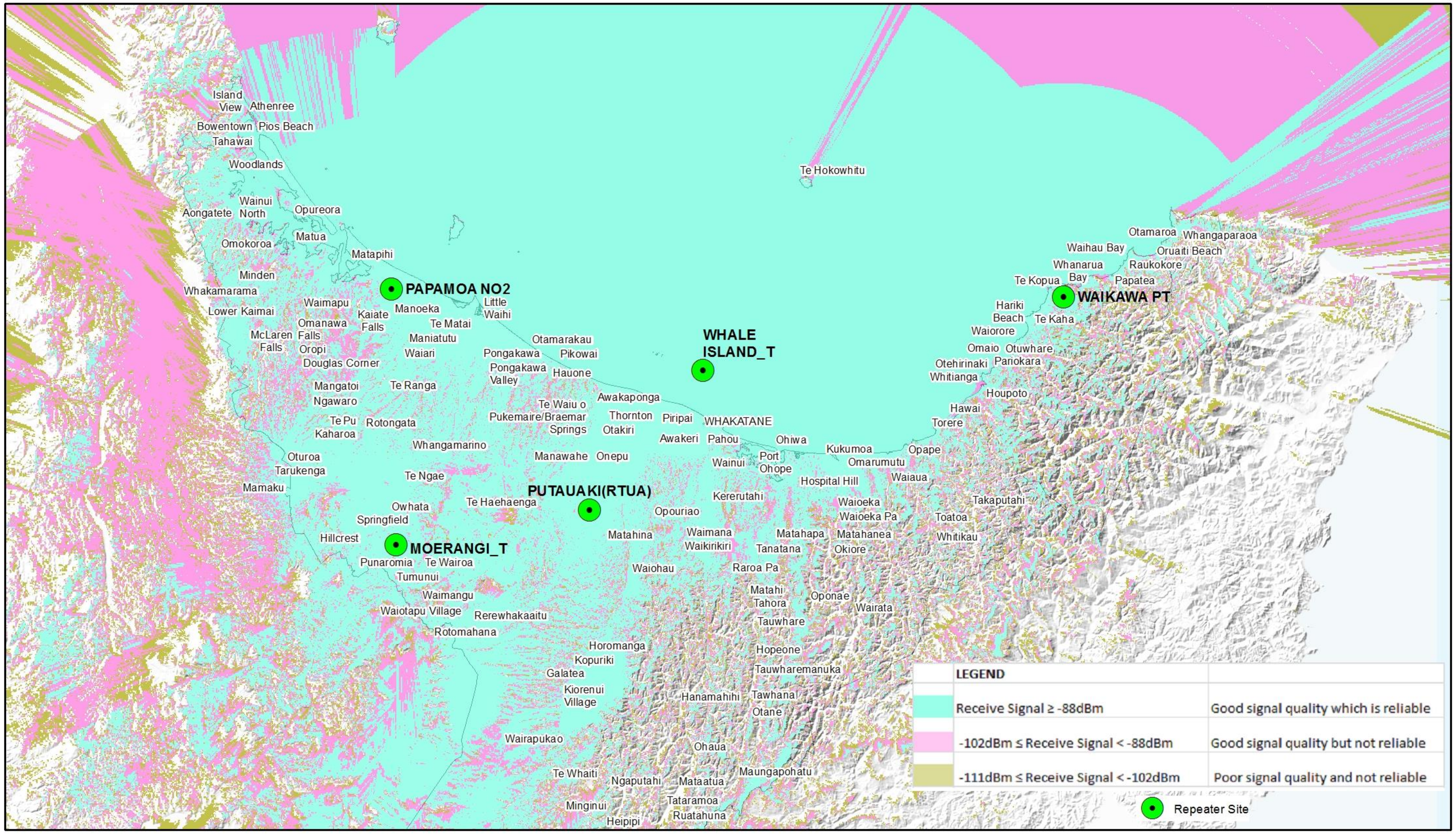
Radio Telephony Coverage - Combined Regional Voice

Scale 1:1000000 (A4)

20 0 20 40
Kilometres

GIS-490081
Sheet 10 of 10
Printed 26/02/2015

11. Regional Coverage with five sites



Bay of Plenty REGIONAL COUNCIL

HORIZONTAL DATUM: New Zealand Geodetic Datum 2000
For practical purposes, NZGD2000 equates to WGS84
VERTICAL DATUM: Moturiki
PROJECTION: New Zealand Transverse Mercator 2000

Radio Telephony Coverage - Combined Regional with 5 Sites

Scale 1:1000000 (A4)

20 0 20 40
Kilometres

GIS-490081
Sheet 9 of 10
Printed 26/02/2015

Appendix C: Site Photographs

1. Rangitoto (Whakapoungakau) (now called Rangitoto)

Figure 5: Cabling Inside Equipment Shelter

Figure 6: Radio Equipment Rack 1

Figure 7: Radio Equipment Rack 2 top and bottom

Figure 8: Antenna Pole and Building

2. Putauaki (WRUA)

Figure 9: WRUA Equipment Room

Figure 10: WRUA Antenna Poles

3. Moutohora (Whale) Island

Photos provided by A1 Electronics (Whakatane)

Figure 11: Antenna Pole and Building

4. Ohiwa Peninsula Hill

Figure 12: Antenna Pole and Equipment Enclosure

5. Whanarua Bay

No photos unable to access site during review however site looks very similar to Ohiwa Peninsula.

6. TECT All Terrain Park

No photos unable to access site during review.

7. Papamoa No2

Figure 13: Antenna Pole and Shelter

Figure 14: Inside Shelter Batteries

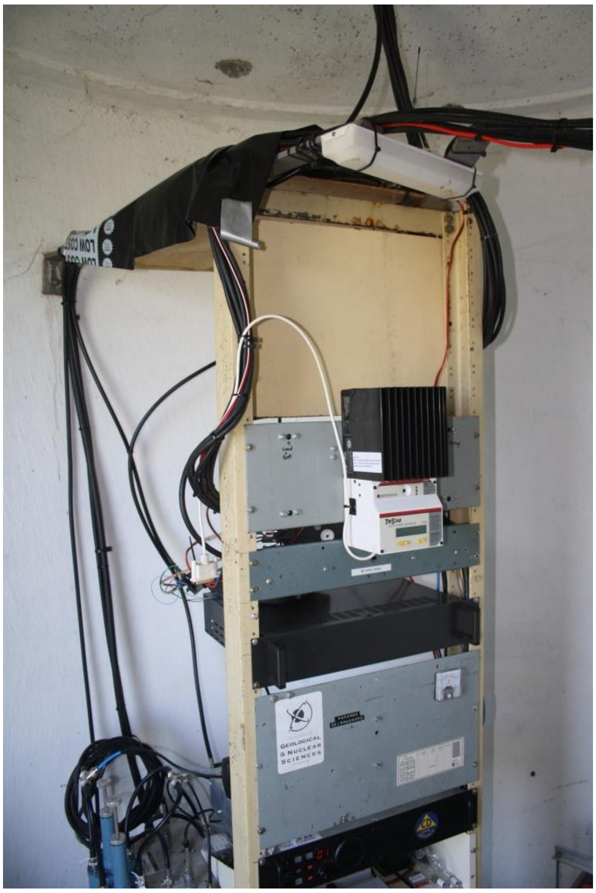

GEOLOGICAL
& NUCLEAR
SCIENCES

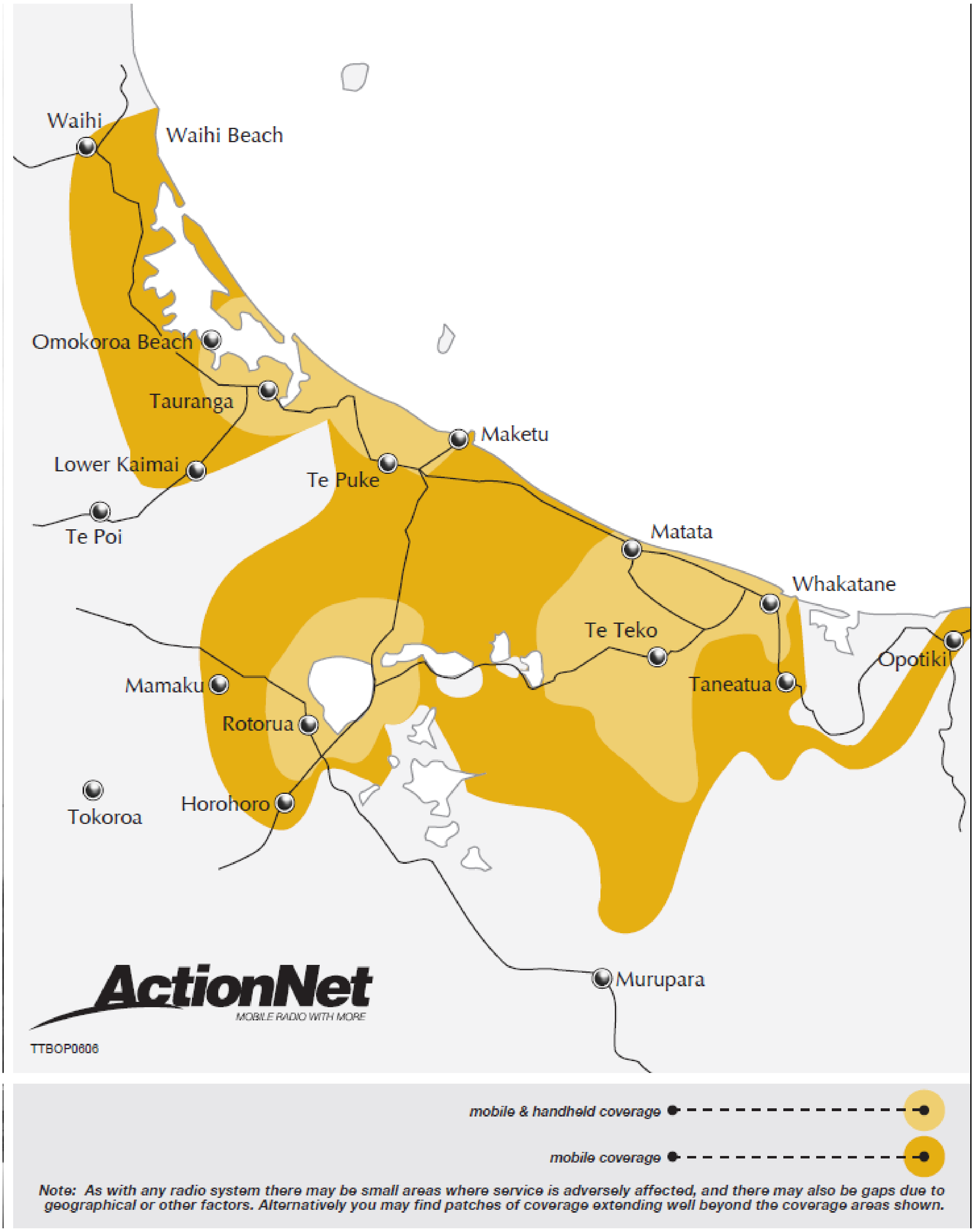
Figure 15: Radio Equipment Rack top and bottom

8. Moerangi

(Note did not have permission to view inside equipment shelter)

Figure 16: Antenna Pole, Equipment Shelter and PV Array

Appendix D: Team Talk Coverage for BOP



Appendix E: PSRFMG rules regarding ES bands

FIRE · CD CIVIL DEFENCE · Ambulance NEW ZEALAND · NEW ZEALAND CUSTOMS SERVICE · Department of Conservation Te Papa Atawbai

PUBLIC SAFETY RADIO FREQUENCY MANAGEMENT GROUP

To Secure and Manage Specific Radio Frequency Bands for the Purpose of Public Safety And Security

15 November 2014

PSRFMG Members

Clarification of Rules to operate within ES Band

In 1989 the Public Safety Radio Frequency Management Group (PSRFMG) was established to secure and manage frequencies for the purpose of Public Safety. Radio Spectrum Management (RSM) set the direction for operating within the established bands of 138 – 144MHz (ESB) and 494 – 502MHZ (ESC).

PIB 58 provides the Policy Rules for any licence to operate within these bands and Section 3.12.3 relates to the conditions for any emergency services licences. They state:-
"Approved persons are required to use the following conditions on all license applications for the ES band. – *"The licence permits radio communications solely for non-commercial public safety and security operations relating to the protection of life and property"* Where the Ministry of Civil Defence & Emergency Management is the licensee there is an additional condition that *"Primary use is for Civil Defence and Emergency Management purposes"*.

The PSRFMG Rules of Operation (Section 5) provides guidance on the technical requirements to operate within these bands in order to ensure interoperability between the agencies involved. These rules agreed by the Ministry of Business, Innovation and Enterprise (MBIE) are:-

1. Only analogue FM or digital APCO P25 – FDMA compliant modulation systems shall be used
2. Equipment must comply with the applicable land mobile standards specified in the MBIE Radio Communications standards notices (ASNZ4295 for analogue and TIA-102 family of standards with particular reference to ANSI/TIA-102.CAAB-C for APCO 25 Phase 1 digital voice and data.
3. Equipment must comply with MBIE ES channelling plans specified in PIB23.

With the rapid development of digital radio and the number of standards now available including DMR, dPMR, NXDN, etc, interoperability is a major concern along with compatibility with the agreed New Zealand PPDR APCO25 standard. Consequently only radio systems complying with the above technical requirements will be licensed to operate on the ES bands. All other digital technologies are required to move to other bands, ie E or F band.

When considering any communications upgrade to digital please ensure that the above requirements are complied with.

Please promulgate this information to all involved in this area of radio communications.

Regards

Bruce Emirali
Chair PSRFMG
Ph +64 4 4960189

Appendix F: Introduction to LMR

(see references 6,7, and 8)

Land Mobile Radio (LMR) - sometimes called Professional Mobile Radio or Private Mobile Radio (PMR) was developed for business users who need to keep in contact over relatively short distances with a central base station / dispatcher - a typical example is a taxi company. LMR is also widely used by emergency services. LMR networks consist of one or more base stations and a number of mobile terminals.

Often a LMR system owned and operated by the same organisation as its users however may also be developed to allow public access (by subscription), and they are then known as Public Access Mobile Radio (PAMR). The users of PAMR systems are usually not the same as the system's owner and operator

1. Requirements for LMR Services

The requirements for LMR can be summed in terms of providing a reliable communication service. Key requirements are:

- Reliability. Many LMR services are used in safely critical systems and so in general LMR users prefer to control their own network. Along with ensuring the service is reliable and secure it also helps to control costs.
- Speech and data transmission capability. Mobile data services are increasingly being used for tracking, Telemetry or information updating services.
- Centralised and decentralised operation. In many organisations, LMR is used to organise users and a central dispatch point/control centre is therefore required. However, it may also be important that users are able to contact each other in the absence of a central control point or even any infrastructure at all.
- Point to point, group calls and broadcast calls. For LMR a flexible group call structure is essential so that users can share information directly rather than having to relay via others. Therefore, group calls, calls involving a number of defined users, and broadcast calls, where the call includes all terminals, are required in addition to point-to-point (single terminal to single terminal) calls.
- Fast call set-tip. Rather than dialling a number to set up a call, with the called party answering a phone LMR systems use "push-to-talk" to activate a call to the dispatcher or user group. With the receiving terminal annunciating the message without an answering procedure. Calls may therefore consist of a sentence or two, and users expect to be connected to the called terminal without delay. This is particularly important in the emergency services where the radio may be used to give urgent commands and the

dropping of the first few words of the message due to delaying in setting up the call might have serious consequences.

- Good coverage. LMR mobile radio users usually have less choice as to where to make a call than a cellular user. The call location is often stipulated by the location of the work the user is undertaking. In the case of a utility this may mean having good coverage over a wide area and for public safety users constraints can be even more severe. LMR use VHF or UHF frequency bands ranging from 70 to 900MHz.
- Long battery life. User maintenance costs money in terms of lost work time in LMR systems, and reliability of service is also important. This compares with public cellular systems where the users are responsible for battery charging

Other requirements that may not be needed in all cases are:

- Security this includes encryption and authentication of radios.
- Call priorities so operators can differentiate between users in terms of different call priorities or qualities of service. For example an emergency call may be able to pre-empt other call types to gain access to the network.
- Communication between networks. Many large companies operate over large areas or with several sites. They may not want to provide the complete network themselves, or they may use different networks on different sites due to equipment replacement cycles or regulators restrictions. Their LMR networks may therefore have to communicate with each other. Also in many circumstances communication with general telephone or data networks is a useful feature.
- Ease or licensing. This issue involves not just the bureaucratic process of obtaining permission to use a radio channel but also the issues of the availability of channels and any coordination which may be required with other users in the same area. The problem of licensing hundreds of different users operating in numerous different areas is much more complex than that of organising a small number of national cellular operators. It is only possible if the LMR radio channels are as self-contained as possible with regard to interference between users.
- Capacity or efficient use of the radio resource. In general for LMR users this not an issue due to the length of the call, and since licences have been relative cheap in most countries.

2. LMR Configurations

Radio Channel Arrangement

Radio communications circuits can be either half duplex where users can either listen or talk but not both simultaneously or full duplex where they can where they can talk and listen simultaneously e.g. cellular.

Full duplex communication is possible using either Frequency or Time Division Duplexing (FDD or TDD). As show in diagram below, FDD uses two different frequencies (duplex frequency pair) simultaneously for each direction of communication.

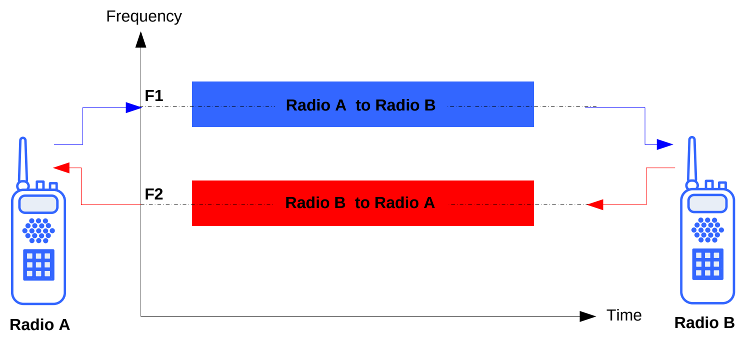


Figure 17: Frequency Division Duplexing (FDD)

Whereas for TDD the same frequency is used for each direction of communication but the frequency is shared in time between each direction e.g.

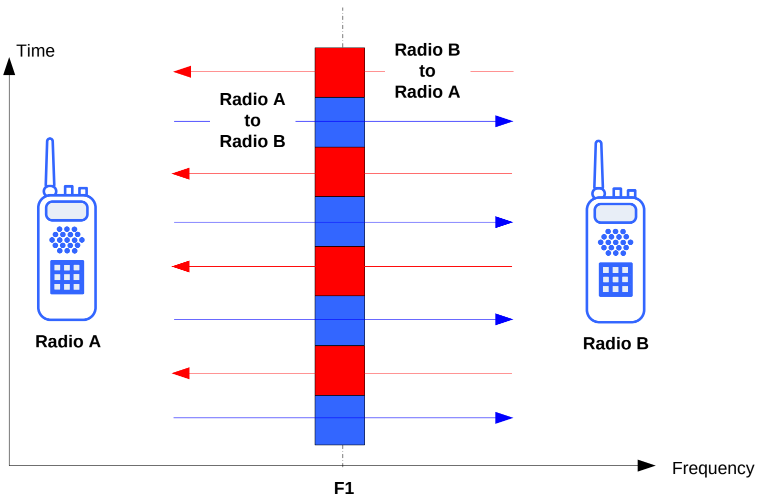


Figure 18: Time Division Duplexing (TDD)

For LMR networks in general communication is half duplex and the radio frequency channel arrangement is either simplex or duplex. In simplex channels the same frequency is used for both transmit and receive whereas for duplex channels two different frequencies are used, one for transmit and the other for receive.

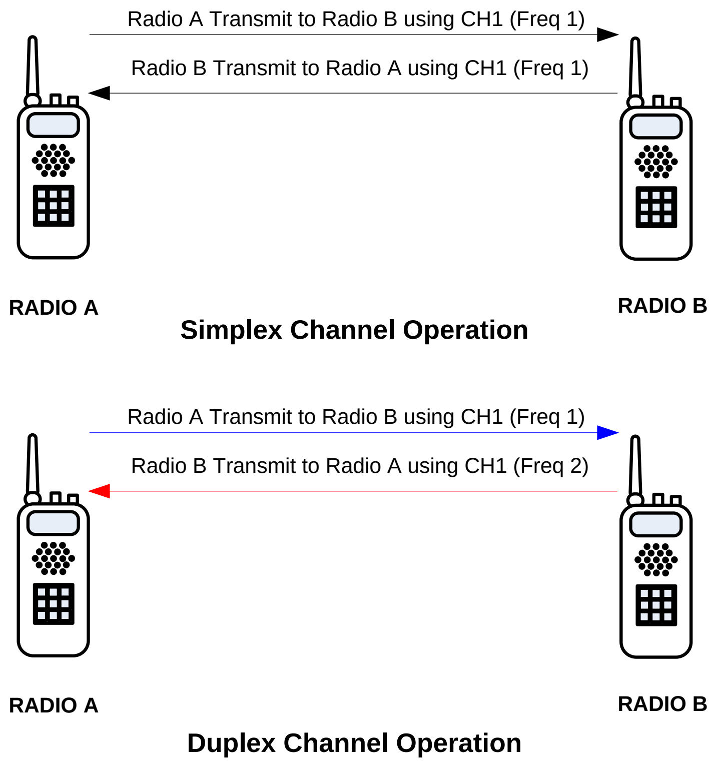


Figure 19: Simplex vs Duplex Channels

With the new digital LMR standards using TDMA full duplex communication is possible using TDD.

Frequency Planning

A LMR network can be can be termed either conventional or trunked depending upon frequency utilisation.

Conventional system is the most basic radio communications system and refers to a "traditional" method of frequency utilisation. Each radio operates on fixed channels with each user group permanently assigned a fixed frequency or a set of frequencies (Channel = Frequency). The radio operates on one channel at a time with correct channel selected by the user. Users can only talk when their channel is clear of traffic otherwise they must wait in "queue" before being able to transmit. The advantages of conventional radio are:

- Simple and cost-effective for sites with a small number of channels.
- Fast call set-up.

The system is limited by the number of frequencies available for a given system. In multi-channel systems, channels are used for to separate purposes. A channel may be reserved for a specific function or for a geographic area. In a functional channel system, one channel may be used for communication between road repair crews and a second channel for communicating between road repair crews and the office. In a geographic system, a taxi company may use one channel to communicate in the northern area and a second channel when taxis are in southern area.

For users who belong to multiple groups using different channels, it is difficult for them to monitor each channel. Therefore automatic scanning is used to scan every assigned channel when the user is not transmitting. The scan will stop when it detects a channel is used and hence the user will be able to automatically follow conversation in different group. Of course, this user can only participate in one group at any one time.

With a conventional system there is a practical limit to number of channels that can be created by adding frequencies and splitting activities geographically. The limiting factors are:

- Availability of spectrum
- Cost of multi-channel operation in terms of radios, antennas and combining equipment this includes running costs e.g. maintenance and power.
- User group radio management and administration.
- Unreliable channel scanning. Scanning and detecting the presence of signals within a channel takes time and it is possible to miss messages if too many channels are scan. For this reason, scan features are either not used or scan lists are intentionally kept short in emergency applications.

For networks where a conventional system isn't a viable option because there are too many users wanting to use the system; a trunking system is used. Trunked radio is discussed in detail in Appendix G:

Modes of Operation

In Conventional networks the following configurations or modes of communication are used:

- Direct Mode
- Dispatch
- Conventional Repeater

In Trunked networks only the repeater configuration is used.

Direct Mode

The direct mode of operation is where one mobile station talks directly to another mobile, or group of mobiles, without going through a fixed base station or repeater. It is also called simplex

since the same frequency is used for both transmit and receive. Either a single common frequency is used or different frequencies can be used for different call groups.

Communication is only possible between radios when they are in range of each other and given the power limitations on battery operated portable radios this may be a significant restriction.

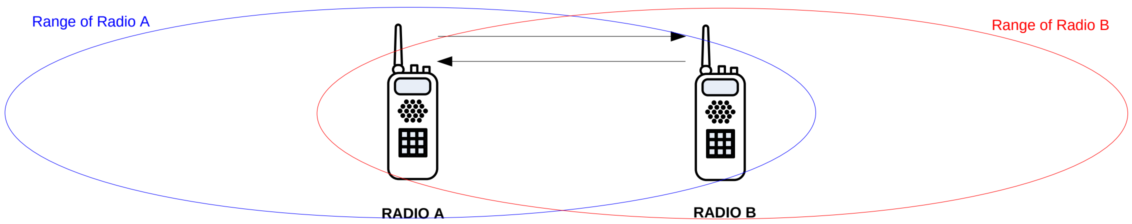


Figure 20: Simple direct mode LMR

Simplex is used typically by organisations requiring temporary communications over relatively small areas e.g. emergency personnel working at a scene of an incident marshals for sporting and other public. Simplex channels are often used for liaison between different public safety agencies.

Dispatch and Repeater Modes

These are the simplest LMR modes that uses fixed infrastructure. It requires a pair of two frequencies, one for uplink communications between the mobile/portable radios and the base station and one for the downlink to the mobile/portable radios. In this operation all mobile/portable radios in the system can hear the base station transmission but mobile/portable cannot hear each other since different frequencies are used for transmit and receive. Only the base station can hear all mobile/portable radios.

In Dispatch mode the base station is connected to the control station where the dispatcher is located. All calls include dispatcher who controls communication and communication between mobile/portable radios is not possible. Links with the public switched telephone or data networks are possible via the dispatcher.

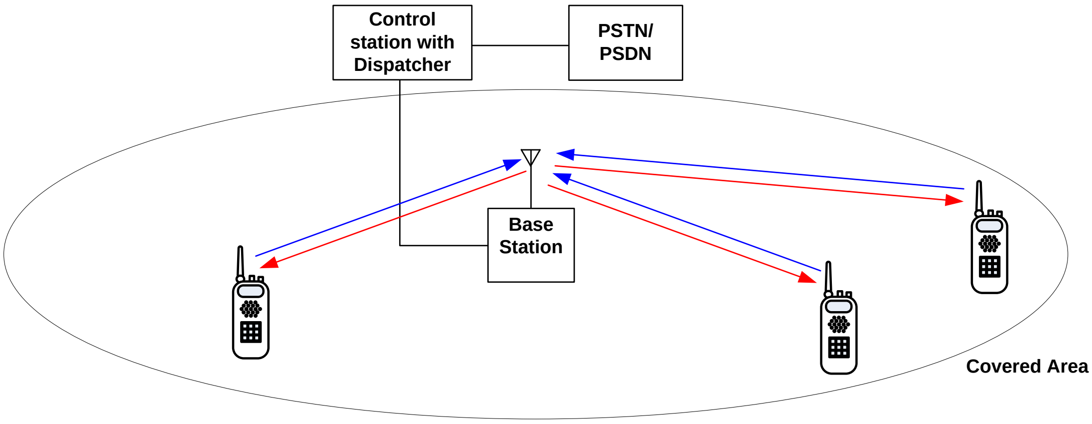


Figure 21: Dispatch mode LMR

In repeater operation ("talkthrough") any uplink messages received by the base station are retransmitted (repeated) on the downlink effectively extending the range of mobile/portable radios. Repeaters are typically sited on a local high point e.g. mountain top, towers, and tall buildings to provide maximum coverage.

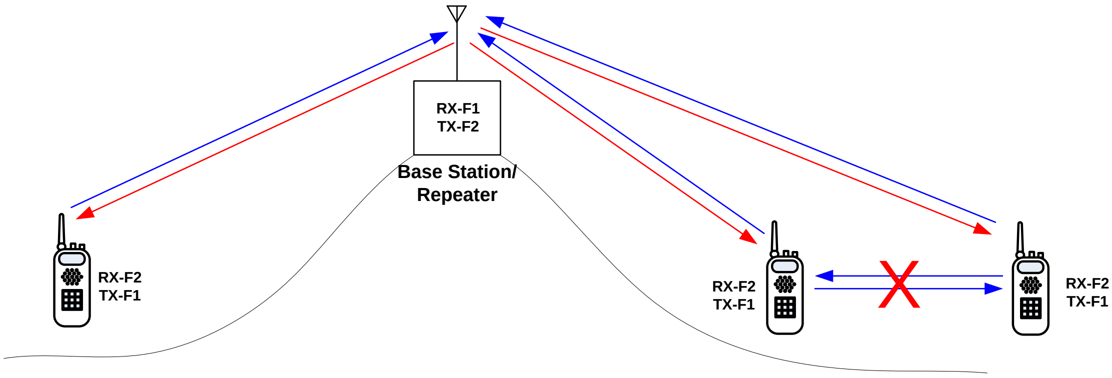


Figure 22: Repeater LMR Mode

Different organisations can share repeaters so-called “community base stations" or "community repeaters" if the different users have signalling to identify their message. The signalling is retransmitted by the base station so that mobiles in other groups are muted and privacy maintained. Since users in groups do not hear all the messages it is necessary to keep usage low to ensure access. Such systems therefore include time outs to ensure that users do not ‘hog’ a channel.

In general most radios include both simplex and duplex channels for direct and repeater operation respectively. They will often include a simplex channel that uses the same frequency as the uplink frequency for a duplex channel so they bypass the repeater and talk directly to mobiles. This is called “talkaround” and is essentially the same as direct mode operation.

3. Coverage

LMR radio operates in the VHF and UHF bands and hence is limited to line-of-sight propagation which implies that you must be able to see the radio your wish to communicate with. However in practice communication beyond this range is often possible due to the diffraction, reflection or refraction of the radio waves.

An engineered LMR radio system will include calculating the coverage for any given base station/repeater which is an estimate of the useful range of communication between it and mobile/portable radios. This range depends on radio propagation conditions, which are a function of frequency, antenna height and characteristics, atmospheric noise, reflection and refraction within the atmosphere, attenuation of the radio signal by obstructions (such as terrain, vegetation or buildings), transmitter power and receiver sensitivity, and required signal-to-noise ratio for the chosen modulation method.

VHF versus UHF

If radio communication is required mostly outdoors then VHF is probably the best choice as it is attenuated less by buildings and terrain. However if radios are used in in a heavily wooded area then often UHF is better than VHF.

If the radios are used mainly inside buildings, then UHF (or even 800 or 900 MHz) is likely the best solution since its shorter wavelength travels through the buildings better. Since there are more available channels with UHF it is more likely that a free channel (less interference) will be found in more populated areas. Also since the range of UHF is also not as far as VHF under most conditions, there is less chance of distant radios interfering with the signal.

Range

In direct mode communication the range is limited to the line of sight path between the two mobile/portable radios.

If a repeater is used then communication is limited to the line of sight path between the repeater and any mobile/portable radio.

When the distance becomes too long, or the coverage provided is too restricted for a single repeater, more repeaters are added. By establishing a series of repeater sites, a chain can be linked together to provide radio coverage over a large area. Unfortunately for analogue linking, every time a signal is “repeated”, some of the quality is lost, thus the number of repeaters that can be linked together in any one line is limited. This is not the case for digital linking.

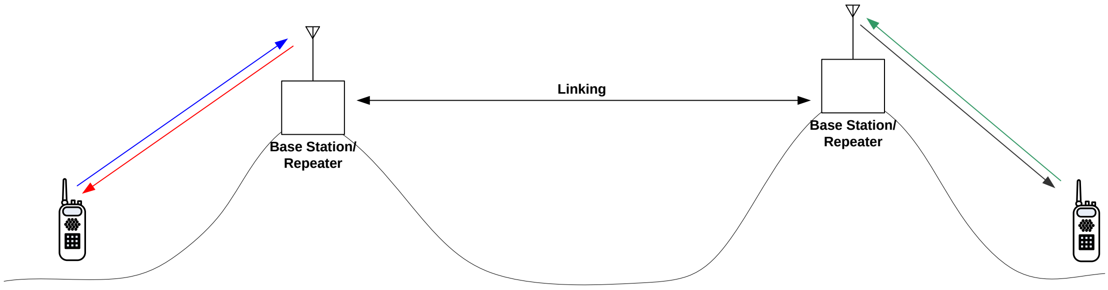


Figure 23: Linked Repeater Sites

The range will also depend on whether a portable or mobile radio is used. Since the transmit power for handheld portable radios (<5W) is less than mobile radios (<25W) mounted in vehicles (due to battery and safety restrictions) then range for portable radios is less than for mobile radios.

4. LMR Design Process

There are many steps to designing a radio system, even a simple repeater system which include:

- Choosing the frequency band and channels to be used.
- Determining the required coverage area and hence where repeater site(s) need to be located. This usually involves a number of trade-offs.
- Selecting the equipment (repeater, duplexer, antenna, batteries, etc.) to be installed.

Appendix G: Trunked LMR

1. Trunking Overview

In Trunking systems is where several channels are shared dynamically between users making it more likely a free channel will available. It is however more complex than conventional systems.

In a trunked radio system, the system logic automatically picks the physical radio frequency channel. There is a protocol that defines a relationship between the radios and the radio backbone which supports them. The protocol allows channel assignments to happen automatically.

Instead of channels, radios are related by groups which may are commonly called talk groups. These can be thought of as virtual channels which appear and disappear as conversations occur as opposed to a conventional system which dedicates a radio frequency to each group.

Digital trunked systems may carry simultaneous conversations on one physical channel. In the case of a digital trunked radio system, the system also manages time slots on a single physical channel (frequency). This is called multiplexing.

A radio may have several talk-groups programmed into it, and the user selects the one he or she wants to use at any particular time.

2. Operation

Radio frequency channels in a trunked system can be divided into two types: traffic and control.

- Traffic channels are what the controller assigns to a user when they wish to speak.,
- Control channels carry instruction and status messages between radios and the controller.

A site typically has one radio frequency set aside as a control channel while the rest are used to carry traffic. Because control channels are transmitted continuously from repeater sites, many systems change the control channel frequency from day to day in order to more evenly distribute the wear and tear on the repeater equipment.

All radios are tuned to the repeater output frequency that carries the control channel. This is called the idle state.

When a group member wishes to speak with the other members of their talk-group, the following steps take place when the user presses the push-to-talk button on their radio:

1. The radio transmits a request along with the radio's current talk-group identifier to the repeater where it is received and forwarded to the controller.
2. The controller checks if there is a traffic channel not currently in use. If there is a traffic channel available, the controller assigns it to the talk-group and marks it

as "in use."
If all of the traffic channels are in use, the controller sends a "busy" message back to the user's radio to inform the user to try again later.

3. The controller sends a message out to all radios, telling them that the talk-group is active on the assigned traffic channel. Radios that receive the message and are programmed with that talk-group tune to the assigned traffic channel.
4. The requesting user's radio receives the message and emits a "go ahead" beep to the user and the user begins speaking.

Steps 1 through 4 happen very quickly, usually in less than one second. Eventually the user stops talking and releases the push-to-talk button and the following steps take place.

5. The user's radio transmits a "finished" message to the repeater where it is received and forwarded to the controller.
6. The controller receives the message and in turn sends a message out to all radios indicating that the talkgroup is no longer active on the assigned traffic channel.
7. Radios that were tuned to the assigned traffic channel retune to the control channel.
8. The controller releases the active channel and marks it as "not in use."

Logic Trunked Radio (LTR)

LTR systems do not have a separate control channel but use a distributed method of access where service may be requested on any channel, and every channel may be used for voice communications. In a five-channel LTR system, all five channels can be used for voice traffic, making more efficient use of the assigned radio frequencies. It also removes the bottleneck that delays messages during periods of heavy use if all access requests are being handled in sequential order by the control channel.

Without a dedicated control channel LTR lacks the centralised control functions required by some users and hence LTR systems are not common in public safety but are often used for industrial and business applications.

LTR systems can have problem with ‘Late Entry” where a user joins a call already in progress after powering on or entering system coverage.

3. Advantages of trunked radio

- More efficient use of frequencies due to the dynamic channel allocation at the call setup.
- Greater control with authenticated user access to the network and its services.
- Channel (Talk Group) capabilities
- Various user features, including Emergency Alarm, PTT ID, Channel Regrouping, Call Alert, and Radio Inhibit

- Suitable for calls involving more than one site, as the trunking controller only includes sites which have participants in the call.
- Sophisticated handling of failure scenarios. For example, the loss of one traffic channel only reduces the capacity of the network by one call; no users lose service. Most vendors offer systems which degrade gracefully if equipment or links fail.
- Consistency in radio coverage

Appendix H: Analogue versus Digital

(see reference 9)

1. Coverage and Voice Quality

Digital has greater voice clarity at low received signal levels near the edge of coverage than analogue which can result in a 20% increase in coverage for digital when compared with analogue.

Signal strength falls off exponentially as the distance from the transmitter increases, following the inverse square law. At the same time, the background RF "noise" level remains constant, so the signal-to noise ratio (SNR) declines by a factor of four with each doubling of the distance between transmitter and receiver. For analogue this decreasing SNR translates into a declining voice quality as FM reception becomes increasingly noisier and intermittent in fringe areas. Whereas digital incorporates built-in error-correction which reconstitutes the voice at nearly its original fidelity throughout most of the RF coverage area. This is shown in the graph below where

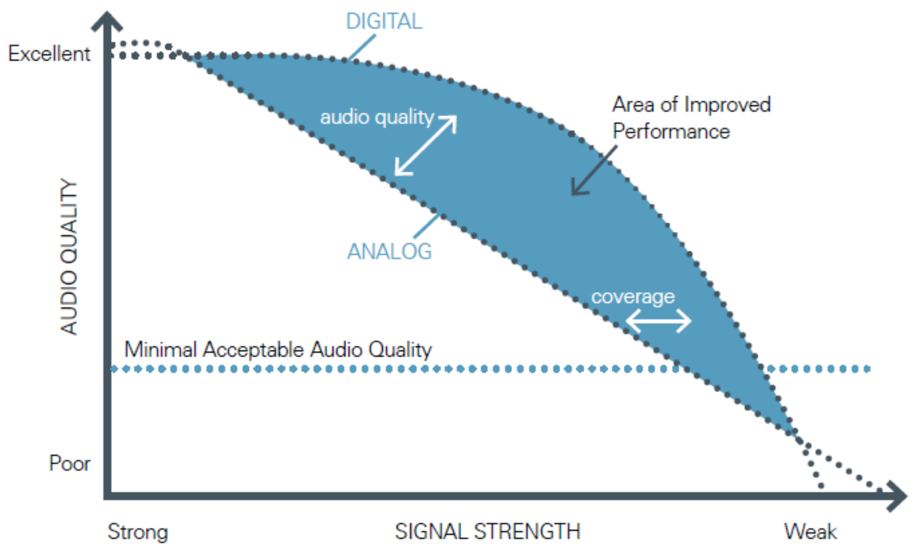


Figure 24: Coverage Performance between Analogue and Digital

One caveat applying to the general statement that digital voice is superior to analogue relates to the use of wide band channels (25kHz) where analogue might be superior in environments with high noise levels. This is background noise can cause distortions in the vocoder (used in digital radios to compress human speech) output. This was the conclusion of 'The Phoenix Fire

Department' after its own testing where it decided to use analogue simplex communications at the fire scene. (ref http://www.ci.phoenix.az.us/FIRE/radioreport.pdf.)

2. Static and noise rejection

Along with the decreasing SNR increasing the static in analogue signals, there are other sources of static which can degrade voice quality in difficult environments. By contrast, digital receivers simply reject anything they interpret as an error resulting in either a brief dropout or bursts of sound which is generally more acceptable than persistent static. Moreover, some digital systems incorporate background noise suppression at the transmitter so background crowd or traffic noise is never transmitted and therefore never heard at the receiver.

3. Encryption

Digital encryption has no effect on voice quality; Analogue scrambling or encryption techniques can degrade it which becomes more noticeable at the edge of coverage.

4. Battery Life

Depending on the device design, digital systems can also improve field operations through longer battery life and additional features. For example, TDMA based systems that provide 6.25 kHz equivalency in a 12.5 kHz channel use only half their transmit time to carry a single half-duplex conversation. Since transmitting RF signals is very power-intensive, this means digital systems place less drain on the battery than their analogue counterparts. TDMA-based digital radios function about 40 percent longer on a battery charge than analogue systems.

5. Spectral Efficiency

For digital LMR systems using either FDMA or TDMA, the same bandwidth (12.5 kHz) that is used to carry one analogue channel can be used to carry instead two digital channels. The two-for-one channel advantage can be used to carry a second conversation, to provide dispatch data in parallel with verbal instructions, to enable enhanced call-control and emergency pre-emption, and for a variety of other existing and future applications.

6. Data over LMR

Both Analogue and digital radio can transfer either voice or data however data is generally not defined in analogue standards leading to proprietary implementations.

Digital systems typically use data rates from 1k2-19k2 bits per second and have the same capabilities to carry data as found in Internet Protocol provided this is done within the bandwidth and protocol constraints of the system. Because of the limited bandwidth available IP data may

have to be compressed and applications designed to minimise the amount of data they need to send

Although LMR networks have primarily provided voice call services, the importance of data is likely to increase. Networks can have dedicated data channels or dual-purpose channels that can handle voice and data, generally giving voice the priority. They are well-suited to provide low-bandwidth data services and to integrate them with voice. Data services can be used by applications such as the following:

- Vehicle location and tracking
- Real time passenger information
- Work force management database access and updates (form based data terminal usage)
- Interactive data messaging (status and text messages).
- Vehicle telematics
- Some simple forms of SCADA (supervisory control and data acquisition)
- Fixed sign updates

The raw data rate of many LMR/LMR standards is 9k6 bit/s, which, after providing forward error correction, slot formatting, headers, and framing, leaves approximately 2k – 6k bit/s for the data application. Unlike voice, data cannot have any errors and may have to be re-sent, reducing the throughput. Hence the coverage for data applications is likely to be less than for voice.

Appendix I: Digital LMR Technologies

(see reference 10)

1. TETRA

Full European Telecommunication Standard status was obtained in 1995. TETRA provides a full set of standards for air and line interfaces. It is established as the default standard for public safety networks in the UK and in Europe. Two years ago the intellectual property hurdles were removed for the United States and TETRA is now aiming to enter the market.

ETSI envisaged networks provided by national organizations, with nationwide coverage, operating usually in urban environments. Consequently, TETRA is more like a cellular telephone system than other professional or land mobile radio standards, and is suited to areas with high volumes of radio traffic. It relies on high user numbers to share the infrastructure cost. Most of TETRA's differences in features from other standards arise from this different purpose.

TETRA does not define an analogue mode of operation. There is no migration path from legacy analogue networks. Operation is trunked; there is also no conventional mode. Initially, TETRA had no direct mode but this has since been rectified, with a number of direct mode options.

TETRA equipment is generally comprehensively tested for interoperability.

2. APCO Project 25 (P25)

APCO Project 25 is an open standard initiated by the USA Association of Public Safety Communications Officials (APCO) and developed by the Telecommunications Industry Association (TIA). It has had strong end user input and although it is United States-based and primarily oriented towards public safety requirements, many countries outside the United States and commercial organisations use it.

Non-proprietary open standard since one of the important aims in developing the standard was to ensure interoperability between different agencies at an emergency scene, as proprietary systems had prevented this in the past.

Very secure end-to-end encryption complies with the USA Homeland Security requirements.

Conventional, trunked, and simulcast options. Combinations of these options can be optimised to reflect customer requirements i.e. trunked in high-density urban areas and conventional in rural areas and supports simplex mode for direct communications outside network coverage.

The standard initially only defined the air interface, but has evolved to cover dispatch interfaces and other interfaces between trunking subsystems, allowing networks from different vendors to be interconnected.

Designed for gradual, phased migration from analogue LMR(FM). Equipment can operate in analogue LMR mode, digital P25 mode, or in dual mode but trunked P25 networks cannot offer analogue LMR services

P25 mandates two 'phases', in the migration.

- Phase 1 uses 12.5kHz for a single digital channel which it means it is compatible with existing narrowband FM systems.
- Phase 2 uses 2-slotTDMA to fit two voice channels into a 12.5kHz radio channel to achieve 6.25kHz channel equivalence

P25 Phase 2 radio standard will be backwards compatible with P25 Phase 1.

3. DMR

There are several levels of the DMR standard (TS 102 361). DMR is divided into three tiers.

- Tier I: Unlicensed – DMR equipment having an integral antenna and working in direct mode (communication without infrastructure).
- Tier II: Licensed, conventional – DMR systems operating under individual spectrum licences working in direct mode or using a base station (BS) as a repeater.
- Tier III: Licensed, trunked – DMR trunking systems under individual spectrum licences operating with a controller function that automatically regulates the communications.

All DMR tiers have a channel bandwidth of 12.5kHz, and two-slot time-division multiple access (TDMA) is used. This means the DMR standard meets the requirement of a 6.25kHz equivalent spectrum usage, which is the narrowband requirement for digital in many countries including NZ.

The standard has been published by ETSI since 2005, and is a mature standard.

DMR already supports direct mode, but it is not as spectrum efficient as it could be. Proposals to enhance direct mode are now being discussed in ETSI TG DMR. At the moment security implementations are proprietary, but proposals on making one proprietary solution available for general use have been agreed.

4. dPMR

The characteristics of dPMR are very similar to DMR, but with some important differences. The modulation is different, and modes replace tiers. The modes are:

- Unlicensed peer-to-peer, Conventional, Low power (500mW) radios with integral antenna.
- Mode 1 Licensed peer-to peer, Conventional Peer-to-peer (direct mode) operation without BSs or infrastructure

- Mode 2: Licensed, Conventional Repeater dPMR systems incorporating one or more BSs for repeating or providing system gateways
- Mode 3: Licensed, Trunking, dPMR systems operating under a managed access mode in systems incorporating one or more BSs.

All modes have a channel bandwidth of 6.25kHz, and uses FDMA to fit two channels within a 12.5kHz channel and hence meets the requirement for narrowband digital in many countries including NZ.

The dPMR standard is newer than DMR and was only published by ETSI in 2009.

5. NXDN

NXDN is an 'open proprietary' air interface protocol drafted by Icom and Kenwood and available to members of the NXDN Forum. It uses the same modulation, same channel bandwidth and same codec as dPMR, but is not interoperable with dPMR.

NXDN supports peer-to-peer operation and conventional repeater, as well as two trunking protocols:

- Original 'Type C' based on dedicated control channel logic architecture
- New alternative 'Type D' protocol based on a distributed control channel architecture.

It is likely that suppliers will support one protocol or the other, not both.

6. 12.5kHz TDMA or 6.25kHz FDMA?

There are two candidate technologies for increasing the capacity of existing 12.5 kHz channels: two-slot 12.5 kHz Time-Division Multiple Access (12.5kHz TDMA) or 6.25kHz Frequency-Division Multiple Access (6.25kHz FDMA). Both methods meet the requirements for greater spectral efficiency compared with analogue i.e. fitting two voice channels into a 12.5kHz channel instead of one with analogue.

- FDMA divides the available bandwidth into separate RF frequency channels, as shown below and one user occupies one frequency (1 voice path per channel).
- TDMA divides a RF frequency channel into number of repeating time slots as shown below and one user occupies one timeslot. A timeslot is in effect a virtual channel. As TDMA frequency channel can only provide two channels, FDMA has to be used to provide additional radio channels.

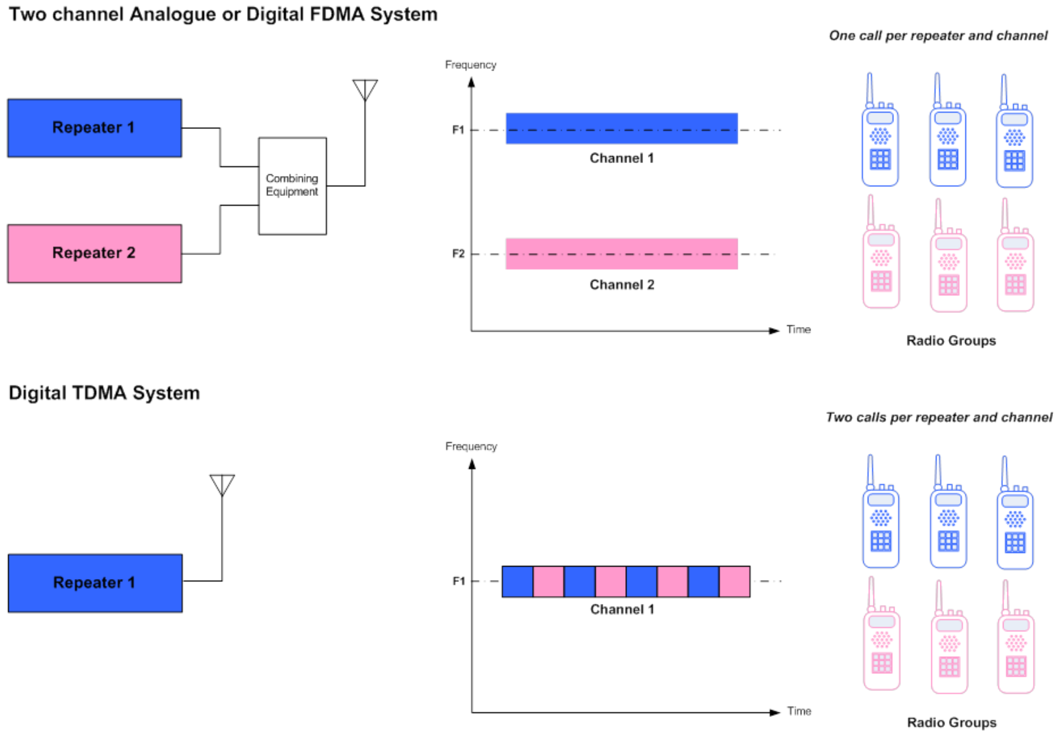


Figure 25: FDMA and TDMA

The choice between FDMA and TDMA has been controversial, prompting debates within standards bodies particularly between DMR (TDMA) and dPMR (FDMA). TDMA is well established, having been used in GSM and TETRA installations for many years, while FDMA for 6.25 kHz is new. Fears that using FDMA with this narrow bandwidth would be technically too difficult have not been substantiated.

Advantage of TDMA over FDMA

- Ease of migration as existing analogue 12.5kHz channel can be retained along with existing combining equipment. For FDMA two new radio channels will be required along with new combining equipment increasing cost.
- For TDMA the wider channel bandwidth compared with FDMA results in a more relaxed specification for transmitter adjacent noise performance and frequency accuracy more akin to analogue LMR. It is also less sensitive to carrier frequencies caused by Doppler Shift when users are travelling at speed.
- Compared with an analogue LMR a 2-slot TDMA radio using one timeslot is only transmitting for half the time. For portable radios, this dramatically reduces battery power consumption, as transmitting is a very power-intensive activity. In a standard operating pattern, (5% transmitting, 5% receiving, and 90% standby), power consumption is reduced by around 40%, greatly extending the battery charge duration and increasing talk time.

When compared with FDMA this less of an advantage since the transmit power of a FDMA radio can be reduced (reducing power consumption) and still obtain the same signal to-noise ratio as the equivalent DMR radio because the modulation bandwidth is less than TDMA. The difference in transmit power is less than the 3dB expected given a FDMA channel is half the width of TDMA because FDMA cannot compress the voice signal as efficiently into the narrower bandwidth.

- Opportunity for reverse channel signalling on the same channel (different timeslot) i.e. from receiving equipment to the sending equipment when it is transmitting. Reverse channel signalling can for example can tell a transmitting radio to stop because an emergency call is waiting, or to inform it of its signal strength so that it can turn its transmit power down or up accordingly.

Disadvantages of TDMA compared with FDMA

- Multipath interference may affect call quality. For the same basic receiver design, TDMA cannot handle as much multipath as FDMA where there is more than one 'propagation' path between the transmitter and receiver. This can cause the received signal to be artificially strengthened or weakened.
- Direct mode (simplex) is not as spectrum-efficient. In some cases, radios may use both timeslots.

7. Summary of Digital LMR Standards

(see reference 10)

	Standard	Business Targeted[1]	Network Size	Analogue or Digital?	C or T[2]?	Modulation	TDMA/FDMA	Vocoder	Vendor: System Name[3]
Conventional Analogue	Yes		Local, Regional	Analogue	C	FM			All
NXDN	No	C	Local, Regional	Digital	C	4FSK	FDMA	AMBE + 2	Icom: IDAS, Kenwood: Nexedge
DMR Tier II	Yes, ETSI	C	Local, Regional	Digital	C	4FSK	TDMA 2 slots	AMBE + 2	Motorola: Mototrbo, Selex: ECOS, Radio Activity
DMR Tier III	Yes, ETSI	B, C	Local, Regional	Digital	T	4FSK	TDMA 2 slots	AMBE + 2	Tait: TaitNet
MPT 1327	Yes (British)	B, C	Nationwide	Digital signalling, Analogue voice	T	FM			Tait, Fylde, Motorola, Simoco
OpenSky	No	A, B	Regional, Nationwide	Digital		4-GFSK	TDMA 4 slots	AMBE	Harris (formerly M/A-COM, Tyco
P25 Conventional Phase 1	Yes, TIA	A	Regional	Digital	C	C4FM	FDMA 12.5 kHz	IMBE or AMBE + 2	Motorola: Smartzone P25, Tait: TaitNet, Harris, Simoco, EF Johnson, Daniels Electronics, Raytheon
P25 Trunking Phase 1	Yes, TIA	A, B	Regional, Nationwide (ISSI)	Digital	T	C4FM	FDMA 12.5 kHz	IMBE or AMBE + 2	Motorola, Tait, Harris, Spectra Engineering, Simoco, Daniels Electronics, EF Johnson, Raytheon, EADS, Teltronic
P25 Phase 2	Yes, TIA	A, B	Regional, Nationwide (ISSI)	Digital	C or T	CQPSK	FDMA 12.5 kHz (backward compatible) and TDMA 2 slots		We expect that Phase 1 providers will develop Phase 2 product.
TETRA	Yes, ETSI	A, B	Nationwide	Digital	T	π/4-QDPSK	TDMA 4 slots	ACELP	Motorola, EADS, Teltronic, Rohill, Rhode & Schwarz and more
TETRAPOL	No	A	Nationwide	Digital	T	GMSK	FDMA 12.5 kHz	CELP	EADS

Notes:

1. A = Public Safety or Mission Critical
   B = Critical Infrastructure
   C = Professional or Business
2. C = Conventional, T = Trunking
3. Examples only: list not exhaustive

Standard	Conventional	Trunked
DMR	Yes (Tier 2)	Yes (Tier 3)
dPMR	Yes (Mode 2)	Yes (Mode 3)
APCO P25 Phase 1	Yes	Yes
AP CO P25 Phase 2	No (will be developed)	Yes
TETRA	No	Yes
NXDN	Yes	Yes

Appendix J: LMR vs Cellular

An important question facing potential LMR users is which option will provide them with the most efficient service: providing the service themselves with LMR using a PAMR provider, or using a standard cellular service provider.

1. Advantages of LMR over Cellular

A two-way radio is typically equipped with a “Push-To-Talk” PTT button to activate the transmitter. User just simply presses the PTT button and can immediately start to talk. User releases the PTT button to listen to others. The key characteristics of this feature are as follows:

- Speed Sub-one-second call set-up (the time it takes for the first volley) and sub-second latency (the time it takes for users to volley back and forth). This key reason why many organisations rely on two-way radio for their tactical or operational communications. If you are using a cellular phone, for example, you need to dial a number, wait for a while when the call is being set-up and connected, ring at the other side and finally answered. This process can take a few seconds and during that valuable time an emergency situation can become worse.
- Simplicity Easy to understand, access and use, as simple as pushing a button to initiate a call. The signal is broadcast to all users within range - anyone with a radio switched on can hear messages, hands free, together with everyone else on the frequency.
- Call Burst Less than a minute in talk time on average, allowing users to 'get things done' quickly without taking the time that is common for typical phone calls
- Group communication (Group Calls) : Another distinct feature of two-way radio is its capability to facilitate “one-to-many” group communication (also known as "group call") very efficiently. By efficient means that one user can talk to one, five, tens, hundreds, thousands of users at the same time. Users don’t need to repeat the same message over and over again if he/she needs to convey to more than one user. In addition, two-way radio performs the group communication using minimum RF channel resources. If all of users reside in the same area, most of the time, you only need one channel resources to talk to these hundreds of users.
  Compare this with cellular network with inefficiencies of scheduling calls, reserving conference bridges, and waiting for participants to join.

Other reasons why LMR have advantages over traditional cellular are:

- Security and specialized dispatching services
- Adequate coverage

- To reduce cost. The costs of two-way radio are fixed. There are generally no on-going line rental charges or airtime costs, users communicate free of charge within the range of the radio.
- To provide supplementary services
- Rugged PTT handsets built with military-grade specifications to ensure durability, coupled with special accessories for ease of operation (e.g., a wireless speaker microphone).

However with the development of good public cellular radio networks the traditional advantages of LMR are challenged. In particular:

- Coverage in cellular system is improving to the point where it can equal and for many users exceed the dedicated coverage provided by LMR.
- The cost of public cellular operation is reducing as well. While LMR is cheaper for large numbers of users or for operations in limited areas the balance is swinging against LMR.
- In the past, LMR handsets operated over a limited range of frequencies perhaps with manual frequency selection, and with very simple call control. This made them far less complex than cellular handsets. The cost advantage is being lost as LMR handsets become more complex with the move to digital and the drive to increase flexibility, capacity and security.
- The relative site of the LMR marketplace means cellular users have the advantages of economies of scale.

It is these factors that have lead some commercial organisations to switch from LMR to Cellular but for many others, particularly emergency services, Cellular is problematic unless it can meet the following public safety communication requirements:

1. Reliability functioning satisfactorily over long periods
2. Resilience functioning satisfactorily under adverse circumstances
3. Push-to-talk / group call with low call setup time
4. Direct communication between terminals
5. Off-network communication (direct mode)

2. Cellular for Emergency Services: LTE

(see reference 1 and 5)

To address the needs for Public Safety, work is underway in Release 12 of 3GPP LTE standards to enhance LTE to address this application in the two following areas:

- Proximity services that identify mobiles in physical proximity and enable optimized communications between them.
- Group call system enablers that support the fundamental requirement for efficient and dynamic group communications operations such as one-to-many calling and dispatcher working.

Associated with these areas will be security features to protect the system from fraudulent users, eavesdropping and other malicious attacks.

Proximity services (ProSE)

Proximity services consists of two main elements: network assisted discovery of users with a desire to communicate who are in close physical proximity and the facilitation of direct communication between such users with, or without, supervision/transiting from the network. This is designed to support the following public safety requirements:

- Off-network operation
- Operation outside network coverage
- Resilience against power outages or major disasters in which network infrastructure is destroyed
- Additional secrecy for covert operations
- Network to terminal relay
- Extending coverage of network infrastructure

The definition of proximity services includes some features that are exclusively for public safety applications in public safety spectrum. In the feature "User equipment to network relay" one mobile acts as a relay for another and provides access to network services outside the normal network coverage area. In the feature "User equipment to user equipment relay" one mobile act’s as a relay point between two others and allows communication to take place without going via the network even if the communicating mobiles are out of range for direct communication.

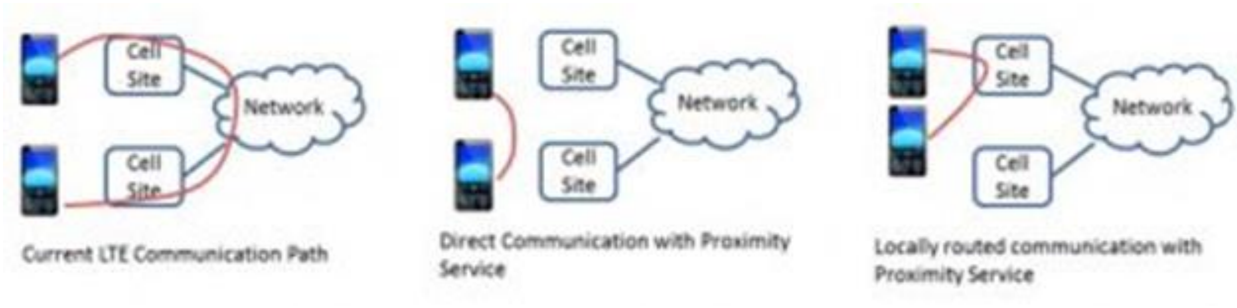


Figure 26: Proximity Service Examples

In the commercial area proximity services can support features like new modes of social networking, convenient file transfer between devices belonging to the same user and targeted advertising. In the commercial context 3GPP's standards will ensure that use of licenced spectrum is controllable and billable by the network operator.

Group Call (GCSE_LTE)

Public safety users frequently need to communicate in dynamic groups that might involve both mobile users on the scene and fixed users ("dispatchers") working in a control centre. Often these groups operate in a "push to talk" mode. Work on LTE group call system enablers will optimize support in LTE for this mode of operation and provide appropriate group management and floor control facilities. Commercial users of group calling include critical communications applications such as operational teams in transport hubs. Improved support for group calling in LTE will expand the opportunity for commercial cellular networks to address this market.

3. Progress

As from mid 2014 the above enhancements to LTE are expected to be available in LTE Release 12 and commercial implementation not until late 2015 as implementations generally lag the Release by a year.

Work is still on going to identify and prioritize other enhancements needed for LTE. Both commercial cellular and public safety systems need to be able to survive network equipment failures and overload situations but the requirements for public safety are more rigorous. In June 2013 3GPP agreed to study how to enhance the resilience of LTE networks for public safety applications.

4. Push to Talk over Cellular (PoC)

(see reference 3)

Push to Talk over Cellular (PoC) is a service that allows subscribers using a commercial cellular network to turn their handset into a walkie-talkie but without the range limitation and high cost

of LMR systems. PoC has been available since 2G(GSM) but it only with 3G/4G that it has been seen as viable alternative to the same service over LMR (PTT).

In 2005, the Open Mobile Alliance (OMA) first defined PoC as part of the IP Multimedia Subsystem and developed the first OMA PoC standard. In 2011, OMA approved PoC v.2.0 as a new standard to take advantage of LTE to provide high performance of IP-based P0C. The goal of OMA-PoC is to provide interoperability among equipment and software manufacturers and avoid market fragmentation by developing the PoC service in a widely standardised manner.

PoC provide the following advantages over LMR:

- Cost savings: Instead of purchasing expensive LMR radios, which typically run between $2000 apiece, organisations can simply add PTT service to an existing cell phone plan at a low incremental cost per user per month.
- Convenience: A mobile worker can carry just one mobile device (a PTT-enabled smartphone or tablet that supports both instant voice communication and data applications).
- Advanced data capabilities: Commercial cellular networks using 3G/4G technologies provide hundreds of times more data capacity than current LMR systems.
- PoC platform supports interoperability with existing LMR networks. A PoC enable cellphone can be used to communicate with LMR radios.

Though the current version of PoC is considered suitable for commercial applications there are reservations regarding it use for emergency services. Hence 3GPP who are working to enhance LTE to meet public safety application requirements are also collaborating with the Open Mobile Alliance (OMA) to define service requirements for push-to-talk functionality over LTE suitable for critical communication use; “Mission Critical Push-To-Talk over LTE” (MCPTT).

6. Cellular Network Resilience and Quality of Service (QOS) Considerations

(see references 2 & 4)

When emergency situations like natural disasters or terrorist attacks happen, demand in telecommunication networks goes up drastically, causing congestion in the networks. This was the experience during recent disasters and terrorist attacks e.g.

- Christchurch Earthquake (Feb 2011).
- Tornado that struck Joplin, Missouri (May 2011) where the cellular systems in that area were off line for up to four days.
- During the 2011 riots and the London bombings in 2005, mobile services across the capital collapsed under the sheer weight of traffic.
- Boston Marathon bombing (April 2013) where commercial networks were unavailable for voice calls because they were overloaded.

If emergency services were reliant on the cellular networks during these disasters then their response would be severely handicapped.

To address this concern and support emergency services (ES) in public cellular networks, ES users need to be identified to provide better guaranteed services including both high admission probability and quicker access than general customers. This can done by using special admission control policies based on access codes presented by ES users at a the base station.

However providing this guaranteed access creates a problem for public cellular networks where its main purpose is providing services for public customers. For these networks to be commercially viable there is trade-off between the costs of providing the necessary infrastructure and passing those costs onto the users. If ES traffic is light, low blocking probability for public use should be guaranteed but if ES traffic becomes unexpectedly heavy then public traffic should be protected through guaranteeing a certain amount of resources for public use. This trade-off in turn could potentially constrain the network in providing the guaranteed service needed by ES,

These admission policies arising from the above considerations may not be deemed to be sufficient by ES users to shift from LMR to cellular as the prime communications network. Therefore in a number of countries e.g. USA and Australia frequency 4G spectrum is being reserved for ES private cellular networks. This spectrum is limited and the cost these networks are high relative to the organisations involved and hence ways of sharing resources between Public and ES cellular networks are being considered (e.g. Australia).

The key principle involved is parallel operation of a public LTE network and an ES network on a common physical infrastructure where the costs of providing network hardening and resiliency

is shared. Capabilities can also be enhanced through different levels of prioritised access for voice and data. This approach can be likened to a motorway with a multi-lane thoroughfare for the majority of traffic (the commercial network) and an additional or reserved transit lane for emergency traffic (ES channel). Ultimately the use of QoS to provide ES traffic access to public spectrum can be complemented by also allowing public traffic to have un-prioritised access to the ES spectrum – essentially allow public traffic managed access to the transit lane when not required by the ES users.

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