

International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Report ITU-R M.2474-0
(09/2019)

**Conventional digital land mobile radio
systems**

M Series
**Mobile, radiodetermination, amateur
and related satellite services**



International
Telecommunication
Union

Foreword

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Note: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.

*Electronic Publication
Geneva, 2019*

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REPORT ITU-R M.2474-0

Conventional digital land mobile radio systems

(2019)

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1 Summary

This Report deals with the technical and operational characteristics of conventional (non-cellular) digital land mobile radio (CDLMR) systems that provide capabilities required for specific user groups/applications, such as governmental, mining, health, hospitality, transportations, disaster relief, industrial, manufacturing, construction, etc. This report also includes information on approaches to frequency assignments for CDLMR.

Digital Cellular Land Mobile Telecommunication Systems, including IMT systems, are addressed in other ITU documents.

Digital Land Mobile Radiocommunication Systems for specific applications, such as PPDR and trunked systems for dispatch, are addressed in other ITU documents.

2 Related Recommendations and Reports

Recommendation ITU-R M.1073 – Digital Cellular Land Mobile Telecommunication Systems

Recommendation ITU-R M.2009 – Radio interface standards for use by public protection and disaster relief operations in accordance with Resolution **646 (Rev.WRC-15)**

Recommendation ITU-R M.2015 – Frequency arrangements for public protection and disaster relief radiocommunication systems in accordance with Resolution **646 (Rev.WRC-15)**

Report ITU-R M.2014 – Digital land mobile systems for dispatch traffic

Report ITU-R M.2377 – Radiocommunication objectives and requirements for Public Protection and Disaster Relief

Report ITU-R M.2415 – Spectrum needs for Public Protection and Disaster Relief (PPDR)

3 Acronyms and Definitions

AES	Advanced encryption standard
AMBE+2	Advanced multi-band excitation
CDLMR	Conventional digital land mobile radio
CLMR	Conventional land mobile radio
CTCSS	Continuous tone-coded squelch system
DCS	Digital code squelch
DES	Data encryption standard
DMO	Direct mode operation
ECC	Electronic Communications Committee
ETSI	European Telecommunication Standards Institute
FDMA	Frequency division multiple access
FSK	Frequency shift keying
GPS	Global Positioning System
IMBE	Improved multi-band excitation
IPv4	Internet Protocol V4
IPv6	Internet Protocol V6
LBT	Listen before talk
LMR	Land mobile radio
PLMR	Private land mobile radio
PPDR	Public protection and disaster relief
PTT	Push to talk
R	Receiver
RF	Radio Frequency
SMS	Short Message Service
T	Transmitter
TDMA	Time division multiple access

Conventional Digital Land Mobile Radio (CDLMR) System: CLMR system that transmits and receives using digital modulation techniques.

Conventional Land Mobile Radio (CLMR) System: Non-cellular radiocommunications system where two or more LMR stations communicate on a predetermined frequency channel(s), without the use

of any controlling station and/or control frequency channel, with push-to-talk and group communications capabilities.

Land Mobile Radio (LMR) System: Analogue or digital two-way conventional or trunked radio communications system in which two or more fixed or mobile radio stations in the land mobile service communicate on one or more frequency (ies).

Private Land Mobile Radio (PLMR or PMR) System: LMR system utilized by a closed group of users to meet specific radiocommunication requirements.

Trunked Land Mobile Radio (TLMR) System: Radiocommunications system where two or more LMR stations communicate on frequency channels assigned by a controlling station automatically from a set of defined frequencies in real time using a radiocommunication protocol.

4 Introduction

This Report addresses non-cellular private land mobile radio (PLMR) communications systems that have been providing two way communications for many industries for decades and are expected to continue to serve millions of businesses and industries around the world. These systems enable flexibility in deployment and can utilise limited spectrum resources to meet the needs of different users. Applications for PLMR include schools, seaports, construction sites, convention halls, factories, retailers and delivery services, etc.

PLMR systems could be trunked or conventional. Trunked LMR systems are described in Report ITU-R M.2014.

The characteristics of digital cellular land mobile telecommunication systems are given in Recommendation ITU-R M.1073.

4.1 Typical CLMR system architecture

CLMR systems can be as basic and simple as a group of users (minimum two sets) operating on an assigned frequency (or frequencies) to communicate in one-to-one or one-to-group mode of communication as shown in Fig. 1 below. A conventional radio system is the most basic and simplest two-way radio system for the user. Two-way radio systems can be configured in many different ways to allow for one one-to-one and one-to-many communication.

CLMR have a common functionality of one-to-one or one-to-many (group) communication by a simple Push-to-Talk. CLMR systems were developed for business users who need to communicate over limited geographical areas but are also widely used for emergency services.

CLMR systems can be categorized into two types: simplex operation for direct peer-to-peer communications; and repeater operation where repeater(s) is (are) used to extend the communication reach.

A CLMR system for simplex operation for a group of users using a common assigned frequency (or set of frequencies) to communicate is shown in Figs 1 and 2 below.

Basic Simplex (Direct mode) or Simplex with Talk around CLMR system

- There is no automated processing of the calls.
- Users simply ‘push-to-talk’ (PTT) on the channel (frequency) they have selected on their mobile or handheld terminals.
- Users have immediate access to selected channel(s) at any time and must listen for a clear channel before transmitting to avoid causing interference to another user in the group.

- The coverage of the basic conventional LMR system is limited by the range of the mobile terminals.
- A fixed base transmitter or repeater is used to increase the range over which users can communicate.
- Talk around mode is when a radio repeats the signal on the same channel with small delay to extend coverage or overcome a field signal obstruction.
- Simplex design (T=R).
- Pros: No infrastructure, low cost, can operate with only single frequency/pair.
- Cons: No wide-area coverage, must relay messages.

FIGURE 1
Basic Simplex One-to-Many Group communication configuration

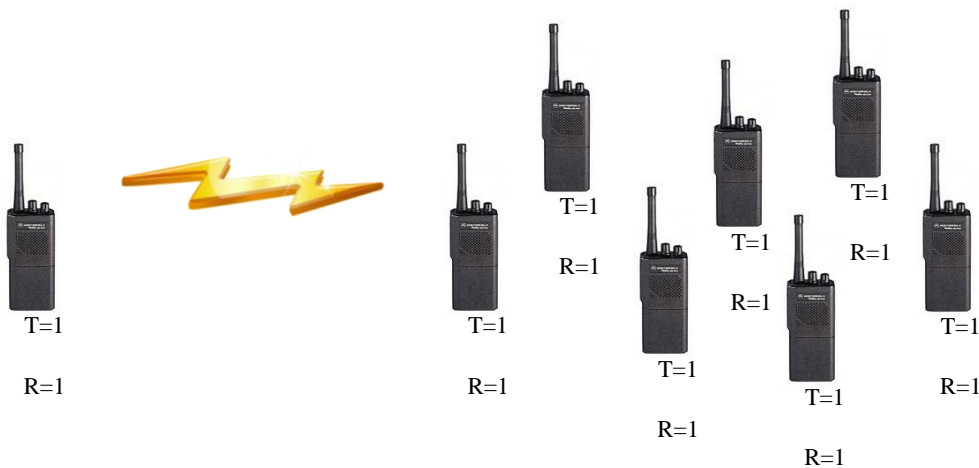
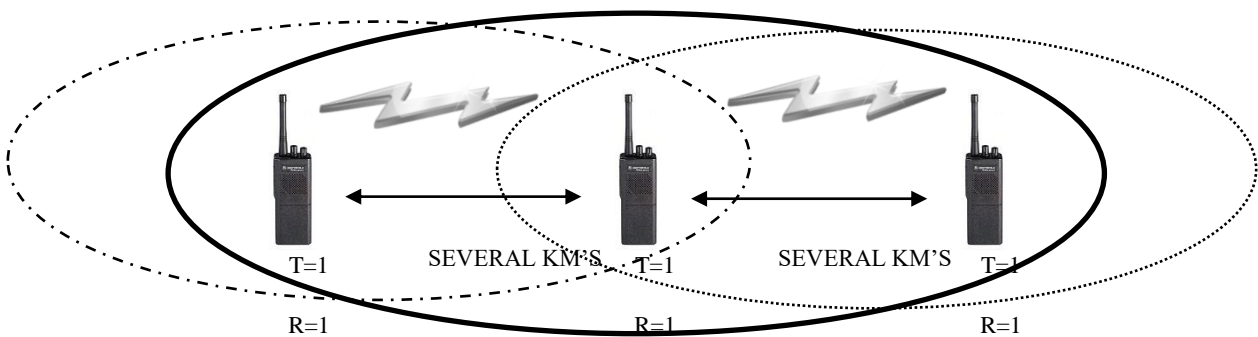


FIGURE 2
Basic conventional LMR system/One to one Direct mode or Talk Around modes of operation

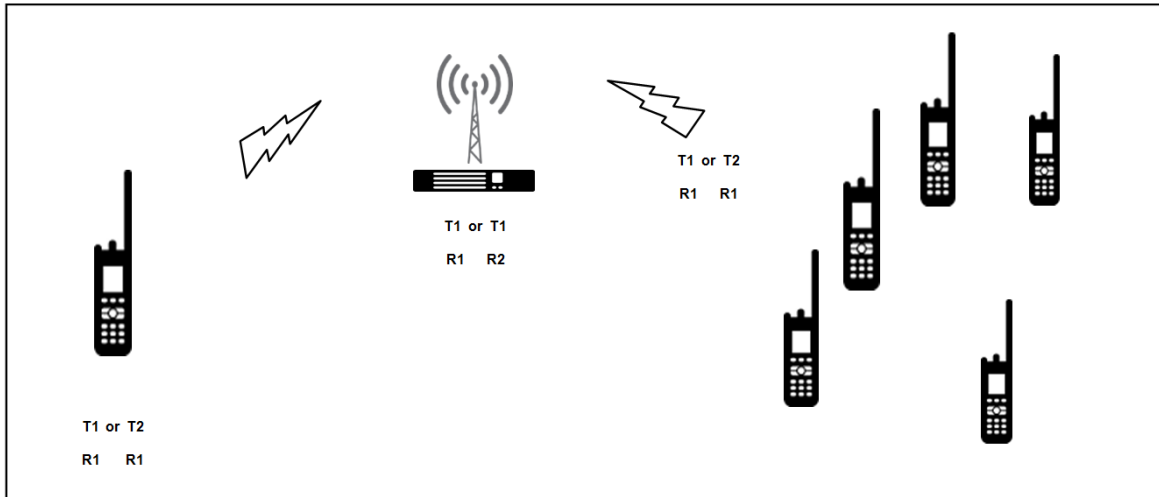


The coverage of a CLMR simplex system is limited by the transmitter range of the mobile terminals used. In a CLMR Talk-Around repeater system, a mobile radio retransmits on the same frequency with a small delay to increase the range over which users can communicate.

Duplex or Simplex with fixed repeater CLMR system

A common CLMR configuration with repeater system enables repeater to either re-transmit on the same frequency or using a second frequency channel. Example of single site CLMR is shown in Fig. 3.

FIGURE 3
Single site CLMR repeater system



- A single-site system is defined as one site with a fixed base transmitter(s)/repeater(s).
- There is no automated processing of calls.
- Two frequencies (one pair) are required per repeater although a single frequency configuration can be used with some systems settings but is not common.
- Fixed repeater base station enables extended coverage and as higher Transmit power is used in the order of 5-20 times that of the mobile radio.
- In Simplex Mode ($R=T$), the fixed station acts as a “repeater” and acts as a simple radio relay. Other mobile units may not hear mobile transmitter if not within range.
- In half Duplex mode, other mobile units will not hear mobile transmitter even if within range ($R \neq T$).

Wide area coverage with multiple repeater sites CLMR system

In wide area coverage CLMR deployments, multiple repeater sites are deployed to provide extended coverage. Repeaters operating independently:

- Subscribers cannot talk across RF boundaries; wide-area coverage for business, but not wide-area communications.
- Manual roaming i.e. users must know RF boundaries and manually change channels as they move from cell to cell.
- A multiple frequency broadcasting design (multicast) enables multiple repeater coverage but allows for communications across RF sites; coverage overlap is not required.

If the CLMR system grows its user base or requires more talk-groups (i.e. more frequency channels), listen before talk becomes a cumbersome protocol as the number of users increase, the channel occupancy mandates additional radio channels (frequencies) hence complex repeaters design to support cascaded repeater in CLMR. The complexity of analogue CLMR multi-channel RF repeater site is at least double that of equivalent digital system. Trunked LMR systems employ automated processing of calls in which a group of frequencies assigned to the trunked radio system is

electronically shared among a large number of users. Trunked systems use access control schemes to share channel capacity among many users. The control channel enables users to take advantage of the fact that some time/frequency channels are idle at a particular time while others are busy and allocate them in a way to maximize utilization.

From their early designs, CLMR systems have developed into ‘trunked’ systems.

The technique also enables multiple base stations to be connected and to provide coverage across a wider area than with a single base station. Report ITU-R M.2014 provides the technical and operational characteristics for spectrum efficient digital trunked systems and also provides details of systems being introduced throughout the world.

4.2 CDLMR

The global trend towards digitalisation of LMR started in the 1990s¹ in radio systems for public safety users, followed by non-public safety users. The adoption of digital LMR technology has grown rapidly in the 2010s and the number of DLMR users exceeded the number of users of analogue LMR for the first time in 2017.

While supporting the introduction of DLMR, consideration also needed to be given to the impact on the large number of existing users employing analogue technology. A 2018 study for global installed base of analogue radios indicates that there is an excess of 20 million subscribers based on analogue LMR.

Many administrations around the world have mandated that PLMR applicants use DLMR systems when applying for new authorizing or renewing existing ones.

4.2.1 Benefits of CDLMR

a) More spectrum efficient than analogue CLMR

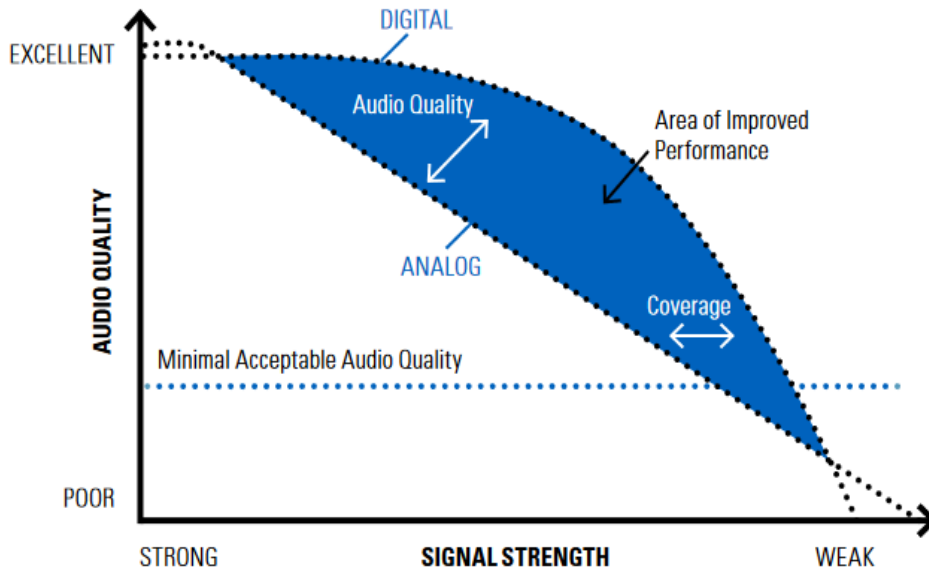
Current digital CLMR technology can support one voice path per 6.25 kHz compared to the 25 kHz or 12.5 kHz per voice path of analogue CLMR.

b) Improved audio quality

In a normal analogue radio, every sound that is picked up by the microphone is transmitted. If there’s a lot of background noise, it can be very difficult to understand the message. Digital technology uses software that focuses purely on voice or data, paying no attention to the machine clatter or the crowd noise around the users. The result is exceptional voice clarity. Radio interference creates static on an analogue radio and makes the conversation less intelligible. Voice gets garbled and the message must be repeated. Because a digital radio has automatic error correction, it rebuilds voice sounds and maintains the clarity of the voice, even if a signal is badly corrupted. And since speech is digitally-encoded, the users benefit from smarter capabilities, such as advanced software algorithms that can deliver clear voice in the most extreme conditions. See Fig. 4 below.

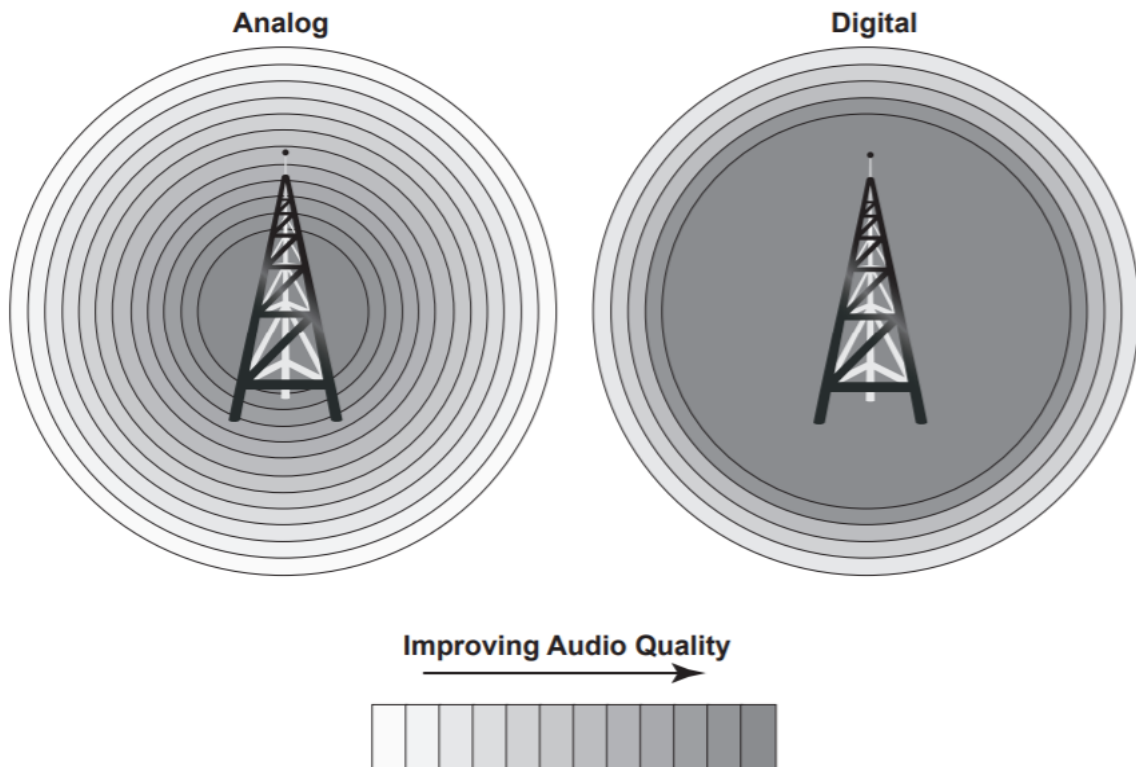
¹ Example: APCO P25, TETRA, TETRAPOLE; followed by DMR, dPMR in the 2000s.

FIGURE 4
Audio quality: Digital vs. Analogue



For any given audio quality, digital radios provide greater usable range than analogue radios, when all other factors are considered equal (for example, transmit power level, antenna height, receiver noise figures, intermediate frequency (IF) filter bandwidths, no additional audio processing, on the analogue radios, terrain, antenna combining equipment, and others), as shown in Fig. 5 below.

FIGURE 5
Conceptual diagram showing improvements in audio quality with digital PLMR



c) Enhanced communication security

A typical analogue radio require an ancillary encryption hardware to provide voice encryption whereas a digital radio can be configured and programmed to provide voice encryption. Digital voice encryption has become much more secure and efficient. For example, digital LMR standards such as TETRA and P25 have built-in support for air interface encryption.

d) Longer battery life

Digital radios employing TDMA have longer battery performance compared to analogue radios. In TDMA a channel is divided into two or more timeslots and the radio only transmit on one of the timeslots. This allows a digital radio to deliver a longer battery life than an equivalent analogue radio on a single charge.

e) Applications for additional functions

Software applications can be installed in digital radios for additional functional features, such as, for enhanced encryption, dispatch, work order management, location tracking, worker safety and integration with IP networks.

5 General technical and operational considerations

As is the case with other mobile radiocommunication systems (e.g. mobile cellular) the; the operational requirements of professional users have evolved. In addition to spectrum efficiency, digital radio technologies provide: improved audio quality; longer battery performance; and better communication security.

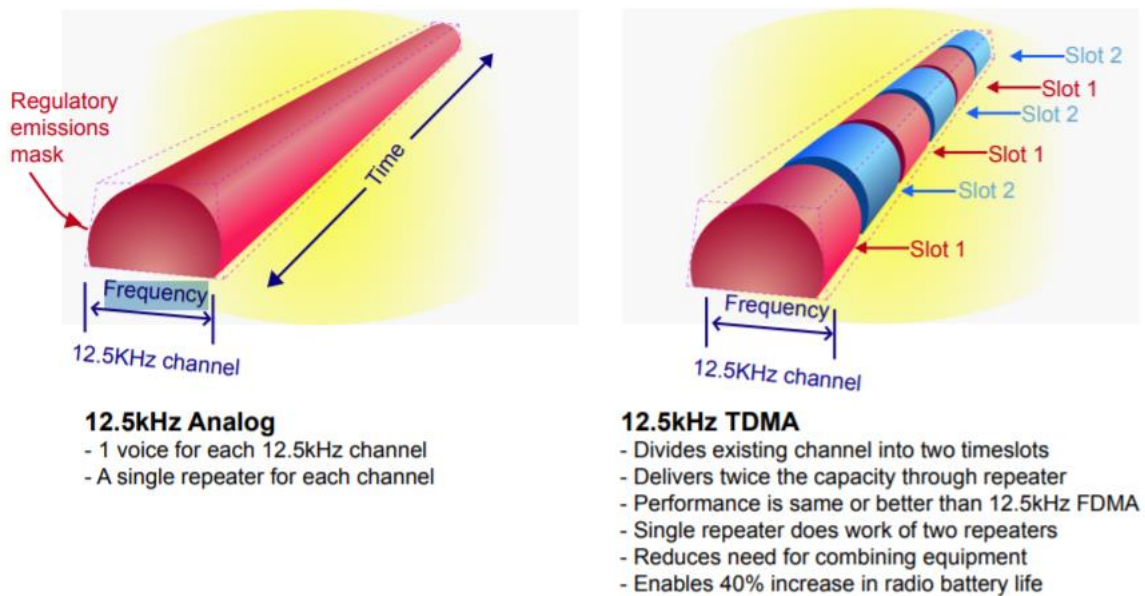
In general the underlying technologies to digital radio protocols used in CDLMR are:

- TDMA: Typically occupies a channel width of 12.5 kHz and divides each 12.5 kHz channel into two timeslots (two logical channels), with each time slot providing a separate communication path.
- FDMA: In contrast to TDMA, FDMA radio protocols provide one communication path per physical channel. For example a 6.25 kHz FDMA radio will operate in a 6.25 kHz channel and provides one communication path.

In the case of CDLMR radios employing 12.5 kHz, these radios have been specified with the intention of allowing the replacement of analogue 12.5 kHz radios in existing LMR bands.

FIGURE 6

Example of benefits of digital over analogue LMR



In cases where existing analogue CLMR systems are upgraded to CDLMR systems using existing channel arrangements the technical and operational considerations for CDLMR are similar to that for analogue CLMR. For CDLMR repeater systems using paired frequencies, the same channel assignment plan may be used as the frequency separation for multiple transmitters located at a site is the same.²

The use of 12.5 or 6.25 kHz channels with digital technologies can provide up to 4 times the capacity compared with analogue 25 kHz systems. Using similar infrastructure, CDLMR systems can be as robust and stable as analogue CLMR systems while providing additional useful features such as better communication quality. Interference issues between analogue CLMR systems is the same as that between analogue and digital CLMR systems; that coexistence issues are similar between analogue to analogue, analogue to digital and digital to digital systems. Technical safeguards (such as CTCSS and channel sensing) can allow coexistence between digital and analogue LMR systems in shared simplex channels. In addition, DLMR Access Control can further increase the effectiveness of protection safeguards by limiting access to the resources of a system including radio channel resources to only authorized users.

6 Systems technical characteristics and operational features and standards

6.1 Systems technical characteristics and operational features

Operation of CDLMR radio equipment is based on open standards such as APCO P25, dPMR and DMR which are designed for dedicated use by specific organizations, or standards such as NXDN intended for general commercial use. Typical examples are the radio systems used by police forces and fire brigades.

² See Section 7.1.

Key features of CDLMR systems include:

- Push-To-Talk (PTT): Is a functionality that is common to all CLMR radios. It is a method in which a single button is pressed to open communication (i.e. transmit mode) and the button is released to listen (i.e. receive mode).CLMR systems are available in two modes:
 - Simplex mode: A single frequency is used for transmit and receive among a talk-group, through PTT. A talk-group here is a frequency channel.
 - Repeater mode: A pair of frequencies are used, one frequency is used for transmitting and the other is used for receiving. PTT ensures that only one frequency is active at a time, for mobile stations.
- Point to multi-point communications, group communications (as opposed to cell phones which are point to point communications).
- Large coverage areas.
- Closed user groups.
- Use of VHF or UHF frequency bands.

When CLMR first started the systems simply consisted of a single base station with a number of mobiles that could communicate with this single base station. These systems are still in widespread use today with taxi firms and many others using them for communication. Many systems operate with the remote or mobile stations being able to hear all the calls being made. This may not always be satisfactory and a system of selective calling may be needed. There are several ways of achieving this, including Dual Tone Multiple Frequency (DTMF) signalling and Continuous Tone Coded Squelch System (CTCSS).

Now facilities such as DTMF and CTCSS provide additional calling selection. Because the base station' antenna may be mounted on a high tower, coverage may extend up to distances of fifty kilometres. This is helpful especially when there is no signal in a public cellular mobile phone. Assignments can be made for operation on a particular channel or channels. The user can then have use of these channels to contact the mobile stations in their fleet.

In general narrow band frequency modulation is the chosen form of modulation, although airport services use amplitude modulation. Typically a deviation of 2.5 kHz is used for FM and this enables a channel spacing of 12.5 kHz to be implemented.

6.2 Standards

The worldwide adoption of open standards optimises economies of scale in equipment supply for many countries. Also, open standards provide increased technical robustness, as they are periodically reviewed by industry.

In general, DLMR systems using open standards helps to ensure backwards compatibility with analogue LMR.

There are a number of standards and technologies that support conventional digital PLMR applications. A short summary of three main DLMR standards are described below:

6.2.1 Project 25 (P25 or APCO-25)

P25 may be used in "talk around" mode without any intervening equipment between two or more radios, in conventional mode where two or more radios communicate through a repeater or base station without trunking or in a trunked mode where traffic is automatically assigned to one or more voice channels by a Repeater or Base Station.

P25 is a suite of standards for digital radio communications. P25 was established to address the need for common digital public safety radio communications standards for first-responders and homeland

security/emergency response professionals. The P25 suite of standards involves digital Land Mobile Radio (PLMR) services for local, state/provincial and national public safety organizations and agencies. Although developed primarily for North American public safety services, P25 technology and products are not limited to public safety alone and have also been selected and deployed in other private system application, worldwide. P25-compliant systems are being increasingly adopted and deployed in many countries. Radios can communicate in analogue mode with legacy radios, and in either digital or analogue mode with other P25 radios. Additionally, the deployment of P25-compliant systems will allow for a high degree of equipment interoperability and compatibility. P25 standards use the proprietary Improved Multi-Band Excitation (IMBE) and Advanced Multi-Band Excitation (AMBE+2) voice codecs which were designed by Digital Voice Systems, Inc. to encode/decode the analogue audio signals. The protocol supports the use of Data Encryption Standard (DES) encryption (56 bit), 2-key Triple-DES encryption, three-key Triple-DES encryption, Advanced Encryption Standard (AES) encryption at up to 256 bits keylength, RC4 (40 bits, sold by Motorola as Advanced Digital Privacy), or no encryption.

6.2.2 TETRA in CDLMR operations

TETRA is a high-performance mobile radio system which has been developed primarily for professional users such as the emergency services and public transport. The TETRA suite of mobile radio specifications provide a comprehensive radio capability encompassing trunked, non-trunked and direct mobile-to-mobile communication with a range of facilities including voice, circuit mode data, short data messages and packet mode services. TETRA supports an especially wide range of supplementary services, many of which are exclusive to TETRA.

TETRA is designed to operate in the bands below 1 GHz with 25 kHz channel bandwidth.

When operated in Direct Mode Operation (DMO), TETRA works as a CDLMR enabling direct mobile-to-mobile communications, mobile repeater outside the coverage of the network or can be used as a secure communication channel within the network coverage area.

6.2.3 DMR

Digital Mobile Radio (DMR) is an open digital mobile radio standard defined in the European Telecommunications Standards Institute (ETSI) Standard and used in commercial products around the world. DMR, along with P25 and TETRA are the main PLMR technologies in achieving 6.25 kHz equivalent spectrum efficiency. DMR was designed with three tiers. DMR tiers I and II (conventional) were first published in 2005, and DMR III (trunked) was published in 2012, with manufacturers producing products within a few years of each publication. The primary goal of the standard is to specify a digital system with low complexity, low cost and interoperability across brands, so radio communications purchasers are not locked into a proprietary solution. In practice, many brands have not adhered to this open standard and have introduced proprietary features that make their product offerings non-interoperable.

The DMR standard specifies two-slot TDMA in 12.5 kHz channels spacing i.e. two voice channels per frequency channel. The standard is still under development with revisions being made regularly as more systems are deployed and improvements that can be made discovered. It is very likely that further refinements will be made to the standard, which will necessitate firmware upgrades to terminals and infrastructure in the future to take advantage of these new improvements, with potential incompatibility issues arising if this is not done. DMR covers the RF range 66 MHz to 960 MHz.

DMR Tier I products (also commonly known as PMR 446) are harmonized for licence-exempt use in the 446.0-446.2 MHz band across Europe³ and in many countries across Africa and Asia. Tier I

³ <https://www.ecodocdb.dk/download/b8797390-4577/ECCDec1505.pdf>.

products are specified for non-infrastructure use only without the use of repeaters. This part of the standard provides for consumer applications and low-power commercial applications, using a maximum of 0.5 watt RF power.

DMR Tier II covers conventional radio systems, mobiles and hand portables operating in PMR frequency bands up to 960 MHz. The ETSI DMR Tier II standard is targeted at those users who need spectral efficiency, advanced voice features and integrated IP data services for high-power communications. A number of manufacturers have DMR Tier II compliant products on the market. ETSI DMR specifies two slot TDMA in 12.5 kHz channels for Tier II and III.

DMR Tier III covers trunking operation in frequency bands up to 960 MHz. Tier III supports voice and short messaging handling similar to TETRA with built-in 128 character status messaging and short messaging with up to 288 bits of data in a variety of formats. It also supports packet data service in a variety of formats, including support for IPv4 and IPv6. Tier III compliant products were launched in 2012.

6.2.4 dPMR

Digital Private Mobile Radio (dPMR) , is an air interface for CDLMR. dPMR is an open, non-proprietary standard that was developed by the European Telecommunications Standards Institute (ETSI) and published under the reference ETSI TS 102 658. A simplified version of the dPMR protocol intended for licence-exempt applications was also published by ETSI under the reference TS 102 490.

dPMR major specification:

- Access method: FDMA.
- Transmission rate: 4,800 bit/s.
- Modulation: four-level FSK.

This is achieved in a 6.25 kHz channel.

dPMR equipment complies with the relevant European standard ETSI EN 301 166..

dPMR supports several voice coding algorithms. Equipment with different voice coding algorithms are not interoperable in digital mode and must revert to analogue FM mode.

dPMR446 radios are licence-exempt products for use in the 446.1-446.2 MHz band within Europe. These are digital only versions of PMR446 radios. dPMR446 radios comply with the ETSI TS 102 490 technical specification and are limited to 500 mW RF power with fixed antennas per ECC Decision (05)12. They are suitable for recreational and professional users over short range. dPMR446 equipment is capable of voice, data and voice+data modes of operation. This means that dPMR446 can provide voice calls, text messaging (SMS), status and embedded data such as GPS position etc.

dPMR Mode 1 is the peer to peer mode of dPMR (without repeaters or infrastructure) but without the limitations of the low power counterpart. It can operate all typical PMR frequency bands and without the RF power limits of dPMR446. As well as offering voice and data, dPMR446 Mode 1 also supports combined voice+data so it is possible to embed data into a voice call or automatically append it at the end of a call.

dPMR Mode 2 operations include repeaters and other infrastructure. This brings extra functionality such as analogue or digital system interfaces which can be IP based. Inclusion of repeaters and base stations means that wide area coverage is possible even more so when multiple repeaters are used. Such multiple repeaters can be managed by dynamic channel selection or they can be part of a co-channel wide area system.

dPMR Mode 3 can offer multichannel, multisite trunked radio systems. This enables better utilization of spectrum and management of radio traffic. Management of the radio system starts from the

authentication of radios that wish to connect. Calls are set up by the infrastructure when both parties have responded to the call request ensuring optimum use of the radio resource. Calls may be diverted to other radios, landline numbers or even IP addresses. The infrastructure managing these beacon channels would be capable of placing a call to another radio whether that radio is using the same site or another site within the system.

6.3 Summary of Conventional DLMR systems features

	TETRA	Project 25 Phase 2	DMR	dPMR
Standardisation body	ETSI	TIA	ETSI	ETSI
Single frequency repeater mode	Yes	No	Yes	No
Direct mode (walkie talkie)	Yes	Yes	Yes	Yes
Channel access	TDMA (4-slot)	TDMA (2-slot)	TDMA (2-slot)	FDMA
Channel width	25 kHz	12.5 kHz	12.5 kHz	6.25 kHz
Effective (equivalent) traffic channel bandwidth	6.25 kHz	6.25 kHz	6.25 kHz	6.25 kHz
Frequency ranges that can be supported (MHz)	< 1 000 Currently 350-470 806 – 869	136-869	66-900	< 1 000

7 Frequency bands

7.1 Frequency bands

PLMR utilizes various frequency bands across regions in the mobile service, subject to regional harmonization measures and national conditions.

In certain countries the frequency bands used for CLMR are 136 to 144 MHz, 146 to 174 MHz, 350 to 470 MHz, 806 to 869 MHz.

7.2 Channel spacing and centre frequencies

Channel raster or channel spacing for CLMR may be 25 kHz, 20 kHz, 12.5 kHz, 10 kHz and 6.25 kHz.

For every sub-band of above frequency bands, centre frequency can be calculated as follows:

$$Fn = F1 + (n-1) \times \text{Channel spacing}$$

where:

Fn : Centre frequency of channel n

$F1$: Centre frequency of first channel

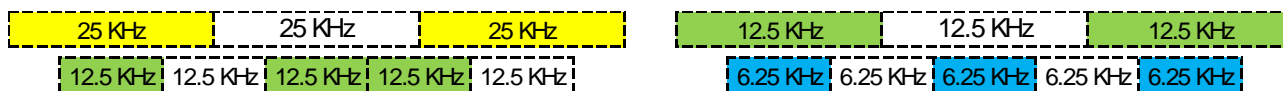
Channel spacing: frequency difference between two adjacent channels

n : channel number; $n = 1, 2, \dots$ and $n < (F_{higher-edge} - F_{lower-edge})/\text{Channel spacing}$.

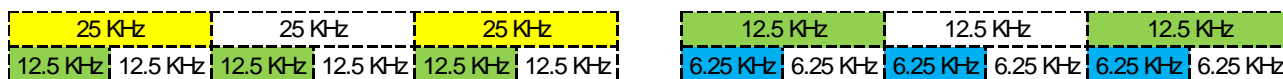
7.3 Channel arrangements

There are two type of arrangements between two channel spacing, i.e. between 25 kHz and 12.5 kHz channels or 12.5 kHz and 6.25 kHz channels, as illustrate below:

- a) Narrow channel located in the centre and the edge of wider channel



- b) Two narrow channel located inside one wider channel



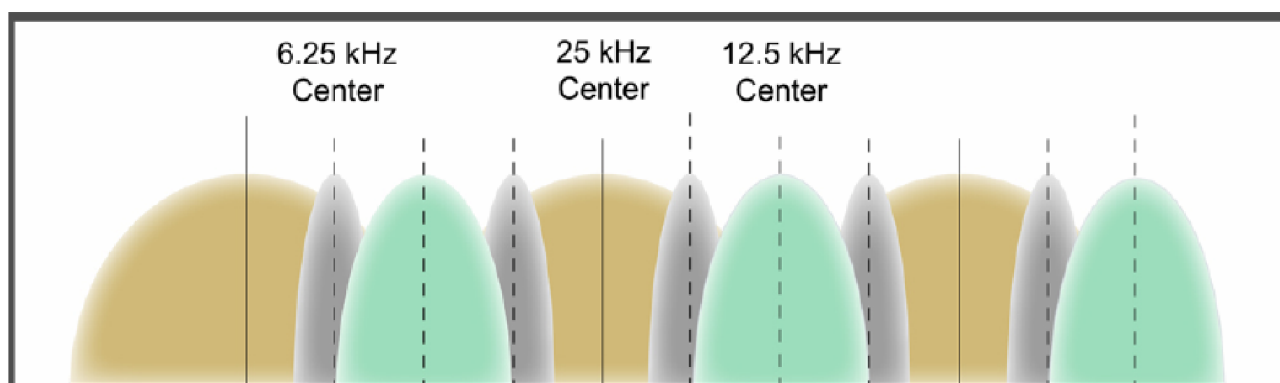
In practice, channelling arrangements for 25, 12.5 and 6.25 kHz could belong to one type or mixed between the above two types.

An example of channelization plan is provided in Annex 1 to this Report.

Channel raster should be compatible with existing channelization and must be technology inclusive to accommodate both TDMA and FDMA technologies, and legacy analogue radios (which have not yet upgraded to digital); and have a well-defined structure for channel frequency spacing. Under this the centre of the channel should remain on the same repeat pattern or “on centre” in the spectrum regardless of the channel bandwidth assigned. Figure 7 below shows how assignments using 25 kHz, 12.5 kHz and 6.25 kHz channelling fit into this general channel structure.

FIGURE 7

Channel structure for LMR bands showing unified channel centre spacing



An example of channelization plan is provided in Annex 1 to this Report.

8 Frequency selection and assignment

This section aims to deal with frequency selection for systems operating in intra-Land Mobile Radio Service scenario: methodology, criteria, practice.

Frequency selection criteria across various scenarios is considered: when a new DPLMR system share the frequency with existing PLMR systems; when existing DPLMR require additional channels; and sharing and interference analysis between PLMR system with C/I or I/N .

Technical and operational characteristics of conventional and trunked land mobile systems operating in the mobile service allocations below 869 MHz to be used in sharing studies are found in Recommendation ITU-R M.1808.

8.1 Examples of frequency assignment methods

One method of assignment of frequencies for PLMR systems is through an administrative method, which results in an apparatus assignment.

Apparatus assignments are issued on a first-come-first-served basis and it usually includes RF technical conditions to mitigate interference between radio systems within a band and in adjacent bands.

One method used to reduce intermodulation products and near-far interference issues between systems and within a system is the use of channels that are grouped, with each channel separated from the others in the group by a fixed number of channels.

Annex 3 provides an example of a frequency assignment plan for 25 kHz channels that are separated by 10 channels from each other in a group.

Recommendation ITU-R SM.337 provides the procedures for calculating distance and frequency separations for an acceptable interference level.

The distances between systems for frequency reuse can be calculated using procedures given in Recommendation ITU-R SM.337. Annex 2 provides an example of frequency channel selection based on Frequency-Distance criteria.

To operate digital LMR systems, and where frequency arrangements are based on 12.5 kHz channels, 25 kHz assignments being considered for migration to 12.5 kHz will have to take into account whether the centre frequency of 12.5 kHz channels are aligned with the 25 kHz channels assigned or whether it is interleaved. This is illustrated in Fig. 8 below.

FIGURE 8
Effect of using TDMA technology in an existing 12.5 kHz and 25 kHz channel



A two for one channel capacity increase is gained using TDMA technology, and possible interference issues are reduced (in contrast to the increased potential for interference resulting from splitting a 25 kHz channel assignment into three adjacent 6.25 kHz channels).

9 Analogue to digital transition

When planning to introduce digital PLMR for the first time, considerations for both data and voice applications, channelling plans, type approval and regulatory requirements need to be considered and to ensure the operation of digital radio in existing (or planned) LMR frequency bands.

9.1 Digital Voice and Data

Digital PLMR systems support both voice and data services, in time or in frequency domain. Data applications in PLMR are becoming an important aspect of PLMR applications. In scenarios where analogue only radio interface are included in the national PLMR radio interface requirements, PLMR systems that support both data and voice or improved voice channel will have to wait for changes to benefit from the improved channel usage or to benefit from both data and voice capabilities.

9.2 Transition analogue to digital

The transition of a PLMR frequency band from analogue to digital is straightforward if the existing arrangements (transmit power, channel assignment plan, channel raster, etc.) remain unchanged.

Some administration may wish to re-band an existing PLMR frequency band to use a narrower channel spacing. For example, from existing 25 kHz channel spacing to 12.5 kHz channel space. In this case the transition will include the additional step of re-banding.

9.2.1 Analogue to digital transition in PLMR bands with existing channel arrangements

Digital PLMR equipment that use 25 kHz or 12.5 kHz channel can operate in existing PLMR frequency bands using existing 25 kHz or 12.5 kHz channel arrangements (transmit power, channel assignment plan, channel raster, etc.) In this transition scenario the probability of interference is no worse than for analogue radio.

The table below provides a summary of which category of digital PLMR radio can migrate in existing PLMR bands.

Existing PLMR bandwidth	Category of digital PLMR radio that can migrate into existing PLMR band
12.5 kHz channel arrangements	12.5 kHz digital PLMR
25 kHz channel arrangements	25 kHz digital PLMR

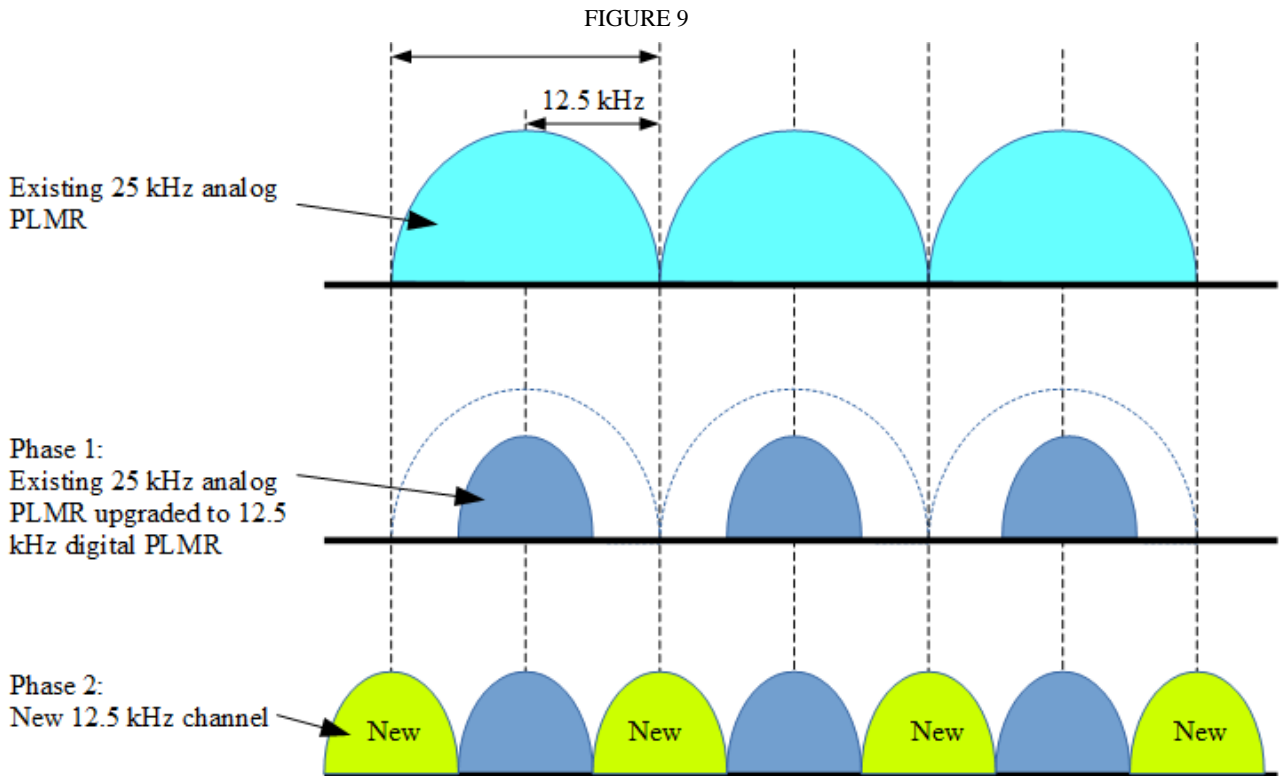
As this transition only involve the upgrade of analogue systems to digital PLMR systems using the same frequencies, much of the existing site infrastructure (e.g. combiner, cabling, etc.) can be re-used.

9.2.2 Analogue to digital transition with re-banding from 25 kHz to 12.5 kHz channel spacing

In this transition scenario a frequency band with 25 kHz channel spacing for analogue PLMR is re-banded to 12.5 kHz channel spacing for digital PLMR.

This type of transition usually implemented in phases. The following transition method consists of two phases. The first phase involves the migration of existing 25 kHz analogue PLMR systems to 12.5 kHz digital PLMR systems using their existing frequency assignments. The second phase involve the retrieving of new 12.5 kHz channels with the completion 25 kHz to 12.5 kHz migration. The migration may take some time before the new channels can be retrieved and reassigned. However it provides a smooth migration without affecting systems that had upgraded to digital PLMR in the first phase.

Figure 9 below illustrates the different phases of the transition.



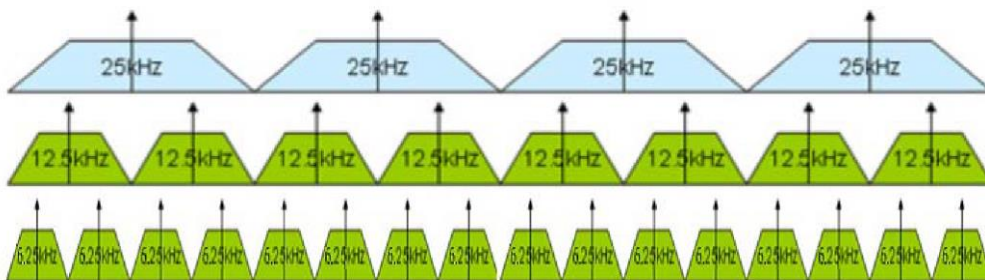
10 Interleaved and offset channelling arrangements

Bands with interleaved channel plans are often suitable for the immediate introduction of DLMR systems, while bands with offset channel plans may require segmentation or transition plans.

10.1 Interleaved channel plans

Interleaved channel plans can provide for the introduction of digital services designed to operate in 12.5 kHz and 6.25 kHz channels without the need for band migrations, provided the selected technology standards are compatible with existing analogue land mobile equipment.

FIGURE 10
Interleaved channel plan



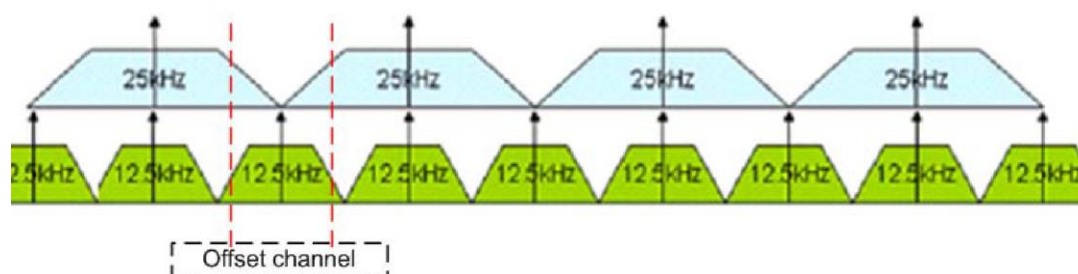
10.2 Offset channel plans

Analogue emissions tend to concentrate their power closer to the centre frequency and within a narrower bandwidth than the channel space assigned in the band (i.e. the effective emission bandwidth in a 25 kHz analogue LMR channel only occupies approximately 16 kHz). Since analogue LMR channels do not spread their power across the entire allocated channel space, it is possible to

assign narrower 12.5 kHz analogue channels (which also concentrate their power in the same way) in the offset gap between 25 kHz analogue channels, without causing harmful interference (as shown in Fig. 11).

Unlike analogue emissions, digital emissions tend to spread their power across the entire channel, and therefore mixing digital and analogue emissions in offset bands can cause adjacent channel interference (from digital into analogue). Therefore, offset bands require either band segmentation or migration plans to be implemented to protect existing analogue services.

FIGURE 11
Offset channel plan



The use of transition plans is seen as an appropriate approach for offset channel plans.

Annex 1

An example of frequency bands and channel spacings for CLMR systems

1 Introduction

The selection of frequency bands for CLMR systems is subject to regional harmonization measures and national needs. CLMR systems are typically found below 1 GHz in the VHF and UHF bands. Of the channel spacings: 6.25 kHz, 10, 12.5 kHz, 20 and 25 kHz; the more common ones in use are 6.25, 12.5 and 25 kHz.

2 Example of frequency bands and channelling

The frequency band 138-174 MHz in the VHF range and 406-470 MHz in UHF range are widely used around the world for CLMR. Channel spacing in those bands are 25/20/12.5/10/6.25 kHz. An example of channelization of CLMR frequency bands is given below.

No	Band (MHz)	Centre frequency (MHz)	Channel number (N)	Channel spacing (kHz)
VHF range				
1	138-144	$138 + 0.025 \times N$	0 to 240	25
		$138 + 0.0125 \times N$	0 to 480	12.5
		$138 + 0.00625 \times N$	0 to 960	6.25
2	146-149.9	$146 + 0.025 \times N$	0 to 155	25
		$146 + 0.0125 \times N$	0 to 310	12.5
		$146 + 0.00625 \times N$	0 to 620	6.25
3	150.05-156.4875	$150.05 + 0.025 \times N$	0 to 257	25
		$150.05 + 0.0125 \times N$	0 to 514	12.5
		$150.05 + 0.00625 \times N$	0 to 1028	6.25
4	156.8375-174	$156.850 + 0.025 \times N$	0 to 686	25
		$156.850 + 0.0125 \times N$	0 to 1372	12.5
		$156.850 + 0.00625 \times N$	0 to 2744	6.25
UHF range				
5	406-430	$406 + 0.025 \times N$	0 to 960	25
		$406 + 0.0125 \times N$	0 to 1920	12.5
		$406 + 0.00625 \times N$	0 to 3840	6.25
6	440-470	$440 + 0.025 \times N$	0 to 1200	25
		$440 + 0.0125 \times N$	0 to 2400	12.5
		$440 + 0.00625 \times N$	0 to 4800	6.25

NOTE – Due to local regulation, some portions of frequency bands listed may not be available in some countries.

Annex 2

An example of frequency channel selection for CLMR systems using Frequency-Distance Criteria

1 Introduction

Traditionally, CLMR systems have usually been based on some popular technical standards for the equipment, but operated under assignment and subject to national frequency management plans.

As the demands for CLMR are high, it is necessary to make effective use of the channels available. This is achieved by re-using the frequencies in different areas. Base stations must be located sufficiently far apart so that interference is not experienced, and also selective calling techniques such as CTCSS and DTMF are used to ensure that as many mobiles as possible can use a given channel.

Selection of a frequency channel for a CLMR system involves the determination of a frequency channel that can be used without causing interference to or receive interference from existing CLMR systems.

One method used is the frequency and distance separations method (F-D method) described in Recommendation ITU-R SM.337. The F-D method is used to assess the potential for interference between the proposed frequency and the frequencies used by existing systems, with intermodulation interference taken into account, when assigning a frequency channel to CLMR system.

The frequency channel that satisfies the F-D criteria and meet the proposed network's operating frequency requirements as far as practicable is assigned.

2 Frequency – Distance criteria

2.1 Deployment model

There are three popular types of CLMR deployment:

- a) Type A:
 - Only handheld transceivers
 - Low output power: typical maximum 5 W to 10 W
 - Single frequency, simplex: transmit and receive in same frequency
- b) Type B:
 - With repeater station(s) and mobile stations
 - Height output power: typical maximum 25 W to 50 W
 - Single frequency, simplex: transmit and receive in same frequency
- c) Type C:
 - With repeater stations and mobile stations
 - Height output power: typical maximum 25 W to 50 W
 - Two frequency, semi-duplex: transmit and receive in difference frequencies

2.2 Minimum distance separation between two CLMR system type A

a) For VHF range

Δf between new 6.25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	10	10	10
6.25 kHz	1.9	10	10
12.5 kHz	0.3	0.5	10
18.75 kHz	0.3	0.3	0.8
25 kHz	0.3	0	0.4
31.25 kHz	0	0	0
37.5 kHz	0	0	0
43.75 kHz	0	0	0
50 kHz	0	0	0

Δf between new 12.5 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	10	10	10
6.25 kHz	10	10	10
12.5 kHz	0.5	1.2	10
18.75 kHz	0.3	0	1.2
25 kHz	0	0	0.4
31.25 kHz	0	0	0.3
37.5 kHz	0	0	0.3
43.75 kHz	0	0	0.3
50 kHz	0	0	0.3

Δf between new 25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	10	10	10
6.25 kHz	10	10	10
12.5 kHz	10	10	10
18.75 kHz	0.8	1.2	10
25 kHz	0.4	0.4	0.6
31.25 kHz	0.4	0.4	0.5
37.5 kHz	0.4	0.4	0.5
43.75 kHz	0.4	0.4	0.5
50 kHz	0.4	0.4	0.5

b) For UHF range

Δf between new 6.25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	10	10	10
6.25 kHz	1.9	10	10
12.5 kHz	0.3	0.5	10
18.75 kHz	0.3	0.3	0.8
25 kHz	0.3	0	0.4
31.25 kHz	0	0	0
37.5 kHz	0	0	0
43.75 kHz	0	0	0
50 kHz	0	0	0

Δf between new 12.5 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	10	10	10
6.25 kHz	10	10	10
12.5 kHz	0.5	1.2	10
18.75 kHz	0.3	0	1.2
25 kHz	0	0	0.4
31.25 kHz	0	0	0
37.5 kHz	0	0	0
43.75 kHz	0	0	0
50 kHz	0	0	0

Δf between new 25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	10	10	10
6.25 kHz	10	10	10
12.5 kHz	10	10	10
18.75 kHz	0.8	1.2	10
25 kHz	0.4	0.4	0.5
31.25 kHz	0	0	0
37.5 kHz	0	0	0
43.75 kHz	0	0	0
50 kHz	0	0	0

2.3 Minimum distance separation between two CLMR system type B

a) For VHF range

Δf between new 6.25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	140	140	140
6.25 kHz	90	130	136
12.5 kHz	33	51	106
18.75 kHz	33	30	64
25 kHz	26	23	48
31.25 kHz	17	15	47
37.5 kHz	17	15	47
43.75 kHz	17	15	47
50 kHz	17	15	47

Δf between new 12.5 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	140	140	140
6.25 kHz	130	130	135
12.5 kHz	51	76	118
18.75 kHz	30	22	76
25 kHz	23	16	48
31.25 kHz	15	8.6	46
37.5 kHz	15	8.6	46
43.75 kHz	15	8.6	46
50 kHz	15	8.6	46

Δf between new 25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	140	140	140
6.25 kHz	136	135	135
12.5 kHz	106	118	118
18.75 kHz	64	76	82
25 kHz	48	48	56
31.25 kHz	47	46	51
37.5 kHz	47	46	51
43.75 kHz	47	46	51
50 kHz	47	46	51

b) For UHF range

Δf between new 6.25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	120	120	120
6.25 kHz	70	110	116
12.5 kHz	8.1	19	86
18.75 kHz	8.1	7.5	44
25 kHz	6.4	5.7	12
31.25 kHz	4.1	3.6	5.1
37.5 kHz	4.1	3.6	4.7
43.75 kHz	4.1	3.6	4.7
50 kHz	4.1	3.6	4.7

Δf between new 12.5 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	120	120	120
6.25 kHz	110	110	115
12.5 kHz	19	57	98
18.75 kHz	7.5	5.4	56
25 kHz	5.7	4.1	13
31.25 kHz	3.6	2.1	4.6
37.5 kHz	3.6	2.1	3.6
43.75 kHz	3.6	2.1	2.4
50 kHz	3.6	2.1	2.4

Δf between new 25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	120	120	120
6.25 kHz	116	115	115
12.5 kHz	86	98	98
18.75 kHz	44	56	62
25 kHz	12	13	23
31.25 kHz	5.1	4.6	7.9
37.5 kHz	4.7	3.6	4.6
43.75 kHz	4.7	2.4	2.8
50 kHz	4.7	2.4	2.4

2.4 Minimum distance separation between two CLMR system type C

a) For VHF range

Δf between new 6.25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	100	100	100
6.25 kHz	52	86	94
12.5 kHz	0	0	63
18.75 kHz	0	0	0
25 kHz	0	0	0
31.25 kHz	0	0	0
37.5 kHz	0	0	0
43.75 kHz	0	0	0
50 kHz	0	0	0

Δf between new 12.5 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	100	100	100
6.25 kHz	86	87	94
12.5 kHz	0	0	74
18.75 kHz	0	0	47
25 kHz	0	0	0
31.25 kHz	0	0	0
37.5 kHz	0	0	0
43.75 kHz	0	0	0
50 kHz	0	0	0

Δf between new 25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	100	100	100
6.25 kHz	94	94	94
12.5 kHz	63	74	74
18.75 kHz	0	47	48
25 kHz	0	0	0
31.25 kHz	0	0	0
37.5 kHz	0	0	0
43.75 kHz	0	0	0
50 kHz	0	0	0

b) **For UHF range**

Δf between new 6.25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	100	100	100
6.25 kHz	54	87	95
12.5 kHz	0	0	65
18.75 kHz	0	0	0
25 kHz	0	0	0
31.25 kHz	0	0	0
37.5 kHz	0	0	0
43.75 kHz	0	0	0
50 kHz	0	0	0

Δf between New 12.5 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	100	100	100
6.25 kHz	87	88	94
12.5 kHz	0	0	75
18.75 kHz	0	0	47
25 kHz	0	0	0
31.25 kHz	0	0	0
37.5 kHz	0	0	0
43.75 kHz	0	0	0
50 kHz	0	0	0

Δf between new 25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	100	100	100
6.25 kHz	95	94	94
12.5 kHz	65	75	75
18.75 kHz	0	47	49
25 kHz	0	0	0
31.25 kHz	0	0	0
37.5 kHz	0	0	0
43.75 kHz	0	0	0
50 kHz	0	0	0

2.5 Minimum distance separation between a CLMR system type A and type B

a) For VHF range

Δf between new 6.25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	116	111	111
6.25 kHz	35	91	103
12.5 kHz	4.5	8	54
18.75 kHz	4.5	4.3	14
25 kHz	3.9	3.5	7
31.25 kHz	2.9	2.6	6.7
37.5 kHz	2.9	2.6	6.7
43.75 kHz	2.9	2.6	6.7
50 kHz	2.9	2.6	6.7

Δf between new 12.5 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	111	105	111
6.25 kHz	91	92	102
12.5 kHz	8	23	70
18.75 kHz	4.3	3.4	23
25 kHz	3.5	2.8	7
31.25 kHz	2.6	1.8	6.4
37.5 kHz	2.6	1.8	5.2
43.75 kHz	2.6	1.8	5.2
50 kHz	2.6	1.8	5.2

Δf between new 25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	111	111	111
6.25 kHz	103	102	102
12.5 kHz	54	70	71
18.75 kHz	14	23	27
25 kHz	7	7	10
31.25 kHz	6.7	6.4	7.9
37.5 kHz	6.7	6.4	7.8
43.75 kHz	6.7	6.4	7.8
50 kHz	6.7	6.4	7.8

b) For UHF range

Δf between new 6.25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	107	103	103
6.25 kHz	34	85	96
12.5 kHz	4.5	8	52
18.75 kHz	4.5	4.3	14
25 kHz	3.9	3.5	6
31.25 kHz	2.9	2.6	3.3
37.5 kHz	2.9	2.6	3.1
43.75 kHz	2.9	2.6	3.1
50 kHz	2.9	2.6	3.1

Δf between new 12.5 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	103	97	103
6.25 kHz	85	86	95
12.5 kHz	8	23	67
18.75 kHz	4.3	3.4	23
25 kHz	3.5	2.8	6.1
31.25 kHz	2.6	1.8	3.1
37.5 kHz	2.6	1.8	2.6
43.75 kHz	2.6	1.8	2
50 kHz	2.6	1.8	2

Δf between new 25 kHz and existing	Distance separation (km)		
	Existing 6.25 kHz	Existing 12.5 kHz	Existing 25 kHz
0 kHz	103	103	103
6.25 kHz	96	95	95
12.5 kHz	52	67	68
18.75 kHz	14	23	27
25 kHz	6	6.1	9.2
31.25 kHz	3.3	3.1	4.4
37.5 kHz	3.1	2.6	3.1
43.75 kHz	3.1	2	2.2
50 kHz	3.1	2	2

Annex 3

An example of frequency assignment plan for 25 kHz channels that are separated by 10 channels from each other in a group

Number of frequencies per group: 8

Separation between frequencies in a group = 25 kHz x 10 = 250 kHz

Number of groups in a block: 10

The number of frequencies in a group depends on assignment plan/policy determining block size.

Group 1	1	11	21	31	41	51	61	71
Group 2	2	12	22	32	42	52	62	72
Group 3	3	13	23	33	43	53	63	73
Group 4	4	14	24	34	44	54	64	74
Group 5	5	15	25	35	45	55	65	75
Group 6	6	16	26	36	46	56	66	76
Group 7	7	17	27	37	47	57	67	77
Group 8	8	18	28	38	48	58	68	78
Group 9	9	19	29	39	49	59	69	79
Group 10	10	20	30	40	50	60	70	80
